TEXT FLY WITHIN
THE BOOK ONLY

THE ELEMENTS

OF

SCIENTIFIC PSYCHOLOGY

BY

KNIGHT DUNLAP

PROFESSOR OF EXPERIMENTAL PSYCHOLOGY IN THE JOHNS HOPKINS UNIVERSITY, BALTIMORE; AUTHOR OF "MYSTICISM, FREUDIANISM AND SCIENTIFIC PSYCHOLOGY," "PERSONAL BEAUTY AND RACIAL BETTERMENT," "NEW AND OLD VIEWPOINTS IN PSYCHOLOGY," ETC.

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TO

EDWARD P. HYDE, PERCY W. COBB, AND
ARCHIE G. WORTHING

OF THE NELA RESEARCH LABORATORIES: REPRESENTATIVES OF A GROUP OF MEN
WHO HAVE BRILLIANTLY ILLUSTRATED THE PRACTICAL VALUE OF
FOSTERING RESEARCH IN PURE SCIENCE

PREFACE

In introducing the student to the modern science of psychology, it is necessary to depart definitely from traditional formulae and traditional conceptions in so far as these formulae and conceptions no longer represent the facts with which psychology has to deal. The psychology of today is a science of the conscious responses of the organism, and as such is called upon to furnish materials applicable to the problems of physical science, education, industry and the arts; and to social problems. Psychology is called upon for these contributions, and is responding: but it is only the modern form of psychology which can contribute effectively. No one thinks today of asking aid in any problem of real life from the psychology, however named, which deals with a peculiar world of psychic objects, by the introspective method, or by any of its later substitutes. One turns instead to the scientific psychology whose subject matter is the world of real objects and real activities, and whose methods are those of all science. It is impossible to put this new wine in the old bottles of phrase and viewpoint which sufficed for its predecessor.

It is necessary, on the other hand, to conserve a large part of the psychological results of the past centuries. Scientific psychology is no new invention, but is a legitimate development from the older psychology which it cannot avoid supplanting, and as such it embodies the achievements of the psychologists from Aristotle to the present generation. With "new psychologies" and with revolts against the essential facts of psychology, scientific psychology has no affiliation, although it represents real progress, and although its postulates in regard to consciousness differ essentially from those of the past.

This book, being designed for the specific purpose of introducing the student to the elements of psychology, and giving him a firm ground on which to build, deals with the general problems of psychology only. The special topics of learning; of child, animal, social and abnormal psychology; of sleep and dreams; and

of applications to education and the arts and industries, are purposely omitted. The student, having mastered the course outlined in this volume, should have available a volume, or a series of volumes, prepared by specialists in these topics, and presenting them from the scientific point of view. No such volume or series exists at present, but we may well expect it in the near future.

The first chapter of this volume is difficult for beginners, and it is possible that instructors will do well to present its most important points in simpler form, and have the students begin their reading with the second chapter. In that case, the students should later return to the first chapter and study it carefully, since it contains the essential scheme of scientific psychology.

The ninth chapter is not intended to be an adequate presentation of the anatomical and physiological facts with which the student should be familiar, but as a résumé of what the instructor should present in greater detail, employing such texts, slides, charts and preparations as may be available. It is not possible to include in a textbook of psychology the portions of physics and the biological sciences required for an adequate study of the subject; and such fragmentary details as might be included are not sufficient.

While written primarily for college students, the book is also designed to be of assistance to men in various professions who wish to become conversant with the foundations of modern psychology. For the book, while dealing with foundations and not with applications, does represent the general point of view on which rests the psychology which is being applied in the fields of education, industry, and the arts, and which will undoubtedly be applied to medicine before long.

A number of the cuts are from new drawings by Olive C. Slater, for whose intelligent and careful work my thanks are heartily rendered. So many persons have helped me by criticism and suggestions and by reading manuscript and proof that I shall not enter here the long list of their names, although I am profoundly grateful for the assistance each has rendered.

KNIGHT DUNLAP.

The Johns Hopkins University,
March 7, 1922.

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CHAPTER I

INTRODUCTION

§1. The divisions of psychology.

It is convenient to divide the field of Psychology into four main parts: (1) Adult Human Psychology, (2) Child Psychology, (3) Animal Psychology, (4) Social Psychology. The first and second parts can each be divided again into, (a) Normal Psychology, and (b) Pathological or Abnormal Psychology. Although this scheme is not the only one which may be used, it is the most convenient one for practical purposes.

It is true that this scheme as given is not an accurate, logical one, as "animal", in the wide sense, includes both the child and the adult human animal, as well as the so-called "lower animal". We actually use the terms to mean *animal other than human.* Social Psychology, again, is usually understood as Human Social Psychology; but it makes extensive use of the results of experiments and observations on animals. We might extend the scheme still further by dividing Animal Psychology into Normal and Pathological, but at the present time there is no practical advantage in such division; whereas there is an advantage in separating Abnormal Human Psychology from Normal Human Psychology. There is an advantage also in separating the psychological treatment of the pathological child—the child which either has insane tendencies, or is mentally deficient—from the treatment of the normal child: but in the case of the lower animal it is not at present useful to study the psychology of the young animal apart from that of the adult. It is also true that there is in Human Psychology an intermediate field between the Psychology of the Child and the Psychology of the Adult, which is frequently given separate

treatment as the Psychology of Adolescence; but this is rather an indeterminate field after all; and, therefore, is not given a special place in this particular scheme. This scheme, in other words, is one determined by convenience, and is not intended to be the ultimate analysis of the whole field.

Adult Human Psychology is the real basis for all the other divisions of Psychology. Child Psychology, for example: the study of the "child mind": is to a large extent an interpretation of the activities of the child in terms of Adult Psychology; and therein lie both the possibility and the danger of Child Psychology.[1] The study of animals from a psychological point of view is an interpretation of animal activity in terms of what we know about the adult human animal; and in this case, as in the study of children, the very nature of the study introduces a serious danger, namely, the danger of hasty and uncritical interpretation.

Social Psychology likewise can be developed only on the basis of a certain amount of knowledge of the psychology of the adult individual. In all three of these subjects, Animal Psychology, Social Psychology, and Child Psychology, the achievements of the present time are not very great. There has been a great deal of speculation in each of them: a great many theories presented in

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[1]The possibility of Child Psychology (and of Animal Psychology) lies in the interpreting of the behavior of the child (or animal) as conscious behavior, when the observable part of the behavior is the same as that which is observed in the adult, and which is assumed to be conscious under similar circumstances. In such inferences, the postulates involved are the same as in the inference from my own conscious reactions to consciousness involved in the reactions of other adults. The danger in Child Psychology and in Animal Psychology, results from the great difference in behavior of children and animals, as compared with human adults, under the same circumstances, although certain outstanding details of the behavior may be the same in the two cases. The danger therefrom is in inferring that the child's (or the animal's) mental processes are the same as those of a human adult under similar circumstances, through failure to note that the child's (or animal's) reactions are not really the same as those of the human adult. The actual determination of the behavior of children and of animals is far more difficult than the determining of the behavior of adults.

It has been assumed sometimes that the child mind may be examined without reference to the adult mind and therefore without the disadvantage of the source of errors in such comparison. This assumption is an unfortunate mistake which has merely served to cover up arbitrary assumptions as to the child's mind. One might, indeed, study child behavior exclusively: but when one discusses perception, thought, and emotional experience in children, one *is* making inferences from the adult mind; so that the only safety lies in being thoroughly cognizant of them as inferences. To deny, in such cases, that one is making inferences, is really to refuse to examine one's inferences: a procedure which leads to serious blunders in theory and in the interpretation of experiments.

the guise of observation: but there is no extensive development of scientific results in any of those three fields such as we find in the basal field of Adult Human Psychology. In the field of Animal Psychology some important experimental work has been done, and a good foundation for future work has been laid. In Social Psychology and in Child Psychology there has been less achievement. That is as we should expect it to be. All three of the subjects wait on the development of Normal Human Adult Psychology, not keeping step with it, but lagging somewhat behind. What has been achieved in these lines, moreover, can be understood only through an understanding of what has been achieved in Adult Human Psychology. There is, therefore, a double reason for paying strict attention at first to Adult Human Psychology.

The relation of Normal Psychology to Pathological Psychology is similar to that of Human Psychology to Child Psychology and Animal Psychology. It has been said frequently during the past twenty years, that the study of Abnormal Psychology—the study of the insane and those on the borderland between definite insanity and sanity—and the study of functional disturbances of the mind, would throw light on Normal Psychology; and that the hope for advance in the latter lay in the study of the former. That hope, however, has not been fulfilled; but rather the development of Pathological Psychology has waited on the development of Normal Psychology. Very little has come back from the study of Abnormal Psychology to Normal Psychology, and a great deal of the theoretical construction in Abnormal Psychology is valuless because it has not been founded on a scientific study of the normal mind. The study of the normal adult human individual is the essential point of beginning for all psychology, but we do not confine ourselves closely to that. In many cases the study of the child, the lower animal and the social group, in the light of what we know about the adult human mind, throws light back on the normal adult human mind, and we find ourselves drawing material from all these fields, for illustrative and clarifying purposes.

There are many minor divisions of the psychological field which have no broad relations to those already described; divisions, moreover, which overlap considerably. We have, for example, *Criminal Psychology,* which includes the study of the actual

criminal, and the study of the individual who is supposed to have criminal tendencies, although he has not developed into an actual criminal. We have also *Educational Psychology,* of which there are various kinds: this field is vague, including what we wish to put into it. In one sense the greater part of psychology is "educational" in that it is constantly concerned with such changes in animals as are produced by training or education. In a more limited sense, Educational Psychology has to do with the learning process, and the manifestation of instinct and emotion: processes which are of maximal importance in our school work.

The *Psychology of Art,* or Esthetics, is another subdivision which has received a certain development, and is receiving more today. The *Psychology of Religion* is a well established branch of psychology, being the study of religion, not from the point of view of theology or ethics, but from that of the emotional and intellectual behaviour and experience of the persons who engage in religious activity. The *Psychology of Sex* which has recently become an important topic, is the study of the mental differences between the sexes, and the effects of these on practical life. Increased knowledge of Sex Psychology is indispensable for the analysis and treatment of many social problems. *Commercial and Industrial Psychology,* a topic which is now being developed very rapidly, is the study of those mental processes which enter into, and are important in, commerce and industry. Bcause of the importance of the practical application of this branch of psychology, and its recognition before there was really much material available for application, there has been much charlatanism in this field.

Comparative Psychology, as the term is now used, deals with the relation between the four fields of Animal, Child, Abnormal and Normal Adult Human Psychology. In the past the term has been applied in a more limited way as a synonym for Animal Psychology. *Genetic Psychology* is the study of the development of mind, both the development of the individual human mind from the fertilized egg to the adult stage, and also the development of mind from the lowest stages of animal life up to the human mind.

Educational Psychology, Commercial Psychology, Criminal Psychology and the practical aspects of Child Psychology and So-

cial Psychology, are included under *Applied Psychology*. Applied Psychology is based on *Individual Psychology*, and involves as an essential part of its method *Mental Measurements*, which is the study of individual differences in mental life. A distinction is commonly drawn between *Experimental Psychology* and Mental Measurements, although the two are intimately related in method and technique.

In mental measurements, the mental capacities and performances of individuals are measured with a view to the comparison of individuals with one another, either for the purpose of selecting certain types of persons for certain purposes (as for admission to college, or employment as telephone operators), or else for the rating of these individuals for some other practical ends. Thus, the mentality of children and adults is measured by the Binet-Simon test to decide whether these individuals are normal, abnormal or mentally defective, and *Educational Measurements* are applied in schools to determine the proficiency and progress of pupils in various curriculum subjects, in which specific tests and scales have been developed. Tests of moral attitudes and other characteristics are being developed.

In Experimental Psychology, although measurements are always made on individuals, the purpose is to discover and analyze traits common to all of the group investigated, the individual differences being difficulties to be overcome by experimental technique, rather than being the main objective. Thus, in studying memory experimentally, the aim is in part to discover laws which determine the process of memorizing and of retention, with the conditions under which memory-work may be made most efficient; rather than to discover the exact differences in memory capacity of the various individuals who are studied.

§2. The nature of psychology.

We have above spoken of Psychology as "the study of the mind." It was formerly defined as "the study of the soul." The word Psychology is derived from the Greek word *psyche*, which meant *the vital principle* or *life essence*. The most ancient treatise on psychology extant is Aristotle's *Peri Psyche*, which is best translated "concerning the vital principle." Because "psyche" has been sometimes translated as "soul", psychology came to be

described as the study of the soul. But the word "soul" has acquired so many meanings that in psychology we no longer use it, although we do not necessarily deny the existence of any of the many things to which the term "soul" is applied. The term *mind,* also, which has been substituted for "soul" in psychology, has become so ambiguous that it is not easy to tell what any writer means by the term "mind" unless it is carefully defined. It is only when we specify precisely what we mean by mind that we can safely define Psychology as "the study of the mind."

Mind is not something which can be sharply separated from body, and body is not something which can be sharply separated from mind, as we use these terms in psychology. In order to explain the use of the term mind, we must consider the individual (whether man, child or animal) as *a complex organism which is stimulated by the environment, and which reacts to the environment.*

When we say that an animal is a complex organism, we mean that it is made up of a vast number of individual cells. A human being does not ordinarily think of himself in that way, but as a matter of fact, the difference between a man and a swarm of bees is not so great as it appears at first suggestion. A swarm of bees is a group of separate individuals, anatomically distinct; yet these bees, in a swarm, with its various sub-groups and various duties, form a machine which functions as a whole in a way in which no single bee can function. The swarm lives, gives birth to new swarms, feeds itself and protects itself from its enemies. Not every bee does all these things, but they are done by the swarm as a whole. The queen lays eggs; but without care, protection and food supply from the workers, the eggs are of no value. So, too, the gathering of honey, and the other functions of the various workers, are of no effect without the functions of all. But with all its members functioning in proper interrelation, the swarm becomes an entity in which the individual bees have their life, and which has its own longer life, in spite of the death of individuals.

The animal body is an aggregate of individuals, most of which are as distinct from each other as are the bees in a swarm. The skin is made up of myriads of individual cells, which can be separated from each other, although the separation usually kills them.

The muscles also are composed of myriads of distinct individual cells. The nervous system, including the brain, spinal cord and parts of the sense organs, is built up of vast numbers of individual cells. Most of these cells are fixed in position; they cannot change their location to any great extent. The muscle cells have power to change their shape, and because of this power of the muscle cells to change their shape, certain parts of the body may change their position, and the body as a whole can move about. There are, however, in the body, some cells which are free to travel about. Certain of these cells, (red blood corpuscles) which float in the blood stream, serve as carriers of oxygen. Other cells (white blood corpuscles) float in the blood stream and also have the power of locomotion, even the ability to leave the blood stream and wander into the other tissues. These cells serve as a police force for the rest of the body, attacking and devouring enemies, such as bacteria. In the heart alone are found cells which are not distinct individuals. The cells of heart muscle are so grown together (*anastomosed*)[2] that it is impossible to distinguish where one leaves off and another commences.

The individual, then, is a complex organism, the parts of which work together harmoniously. If one part of such a body gets out of proper relation to the rest, the body breaks down and may die. The life of all the cells depends on the proper functioning of all of the classes of cells. The unity of the animal body is a unity of function: really a unity of the social functioning of the cells: and mind is one of the products of this social functioning.

Leaving for the moment the conception of the individual as a complex organism, let us consider what we mean by *stimulation.* The animal is surrounded by a mass of details in the outside world which are constantly acting upon it. This mass is the *environment* In physical language, the environment is expending energy on the individual in numerous ways, and some of that energy produces modifications of the body which are called *reactions* or *adjustments,* involving usually contraction or relaxation of muscles or changes in secretion by gland cells. The process by which the environment evokes reactions from the organism is known as *stimulation,* and the specific forces which act on the organism in this

[2]Such a group of anastomosed cells is called a syncytium.

way are called *stimuli.* However, not every application of energy is stimulation. The x-ray is not a stimulus. If you put your hand under an x-ray bulb, there is no immediate reaction, although continued subjection to the rays may kill the skin cells. If, however, you put your hand on a hot stove, the heat causes an adjustment of the organism: you feel the heat and it causes you to move your hand away. So, too, if light falls upon your eyes, or sound on your ear, the energy which is expended on your organism may produce reaction, and the reaction usually includes activity of parts of the body other than the parts stimulated. For example: when light rays fall upon your eyes, you may utter words or move your arms or legs, as a result of the stimulation. All those actions of the environment which produce reactions or adjustment of the body are summed up under that term *stimulus;* and the terms adjustment and reaction indicate the effects of stimuli. A stimulus is an external force which produces an adjustment of the organism.

Some of these reactions or adjustments involve the phenomenon of *consciousness.* Consciousness is one of the terms which have many meanings, and which mean nothing unless carefully defined.[3] There are at present three principal ways in which the term consciousness is used. In psychology we are trying to use it in just one of these ways.

Consciousness, as precisely used in psychology, means merely *awareness* of something, and wherever we find the word *consciousness* we can substitute perfectly the word *awareness.* For instance: when I look at the page in front of me, the situation is expressed in part by "I see the page," or "I am aware of the page," or, "I am conscious of the page." Consciousness is neither the "I" nor the "page." It is necessary to emphasize this, because much confusion has been bred on the point. There are three aspects of the situation involved: the *I,* the *page* which I see, and the fact of

[3]The confusion of terms in psychology is not all the fault of psychologists, and psychology was in existence long before there were any psychologists. Psychology in the past has been developed by men of most diverse types. Philosophers, physiologists, historians, physicists and others have contributed much. The points of view of these different types of men have been various, and they have used terms differently, introducing terms from their own fields, and using the same terms with significations peculiar to these fields. The present state of confusion arose from such conditions, and psychologists are making serious attempts to introduce uniformity.

seeing the page. These three are not identical, although the situation is not complete unless all are present. Another illustration may be drawn from the hearing of something, as when I hear the sound of the train. There is a *sound* heard, there is *hearing* of a sound, and there is *I* who hear. The whole situation in the two cases is expressed by saying, "I am aware of the page," and "I am aware of the sound." *Mental* is the adjective corresponding to consciousness: anything directly connected with, or relating to, awareness, is *mental.*

We can now define psychology in the terms which have been explained. Some of the adjustments of the organism are *conscious*: that is, they include or involve consciousness or awareness: they are mental reactions. Mind, then, is *the totality of conscious adjustments or conscious processes.* The term is used in a concrete way to designate the totality of conscious processes of a single animal, and also, in a more general way, to designate the conscious processes which occur in certain types of animals, or which occur under certain specific conditions. Thus, we speak of your mind, my mind, and a certain's dog's mind; and we also speak of the Child Mind, the Animal Mind, the Insane Mind, the Artistic Mind and the Mediaeval Mind. In a still more general way, we use the term mind without adjectives to designate the sum total of mental processes, whenever and wherever occurring.

In applying the term mind to the life of a single individual, there are various degrees of extension. Genetically, a person's mind is the total of all the conscious reactions which have occurred since the beginning of his organic life. In a more restricted sense, the term may be applied to the group of processes occurring at a given moment.[4]

That which is properly included under the term psychology today is a very definite thing, and has a very definite foundation and course of development. It starts from the empirical situation we have described, in which there is conscious adjustment of an organism to the environment. This total situation, in which there is conscious adjustment, is best designated by the term *experience.* When we consider in detail such a situation, in which we have experience, we find that there are four factors which are to be taken

[4]The Mind at any given moment has been called a *cross-section* of the Mind.

into account.[5] Three of these factors are immediately given as essential parts of the experience, and the fourth is inferred or discovered as a condition of experience. These four factors are:

1. *Something* of which we are conscious. That "something" is called *content.*
2. *Consciousness*, or *awareness* of the content.
3. I, or the *ego*, which is conscious, or has the consciousness.
4. Bodily or organic activity.

Physical science includes among its data only observable facts. Psychological science includes in addition two other facts, the second and third in our list above, neither of which are observable, but which are nevertheless empirical data, in that they are given in experience itself and are not inferences. The inclusion of these data is the only point in which psychology fundamentally differs from physical science, and if we ignore these data, we thereby abandon psychology completely, and go over to strictly physical science.

1. The content of consciousness includes anything of which one is actually aware; but in discussing the general features and laws of content, we must take into consideration everything of which it is possible to be aware. The analysis of content is important

[5]The relations of the conceptions embodied in the foregoing chapter to the conceptions involved in other psychological discussions may be indicated by the following scheme:

1. *Soul:* a substantial, unanalysable "ground" of consciousness.
2. *Ego:* the unity of experience.
3. *Awareness:* including perception and thought.
4. *Content:* that *of which* one is aware.
5. *Physical objects*: considered either as (a) combinations of contents, or, (b) as differing *in kind* from content.
6. *Matter*: as properly conceived by physics: a mathematical statement of the relations of contents to each other, (including time, space, and causal relations).
7. *Material substance:* as conceived by some philosophers and naive thinkers: a "stuff," made up of something which is neither sentiendum nor relation.

In this treatise we do not assume either (1) or (7). Science has nothing to do with either of these. We may consider (2) and (3) together as equivalent to "consciousness": (the knowing of things *together*): the ego being the "con-" and awareness the "-sciousness." But since in normal experience the ego is always involved, we use the terms "awareness" and "consciousness" interchangeably. By *physical objects,* we mean (5,a), but some psychologists evidently mean (5,b), distinguishing "physical objects" from both "content" and from "matter," but holding that we can be directly aware of physical objects as well as of content: a point of view quite incomprehensible to the author.

beyond the mere intrinsic interest in the results of such analysis, because it is possible to describe and discuss adequately the conscious reactions of the organism only by relating these activities to the content which is perceived and thought about through such reactions. An essential part of psychology, therefore, consists in the analysis of content together with the reference of content to physical stimuli.

2. Consciousness or awareness cannot be observed, since it is always and exclusively observation. One does not see the seeing of an object: one sees merely the colors and (in a somewhat loose significance of the word seeing), the form, distance, and other factors involved in the object. While it is obvious that in the act of seeing an object, that of which one is conscious is the object, the seeing being merely the particular way of being conscious of the object, it might be supposed—in fact, has been supposed by some philosophers—that in a later moment one might observe the seeing which occurred in the preceding moment. Such a turning of consciousness upon itself has, however, never been performed even in this retrospective way. If one sees a color or colored object, and then a moment later "thinks" of this experience, that of which he thinks will be either the color which was seen, or some other facts which were not seen but were heard, smelled, tasted or "felt" along with the original object. One is never conscious of the preceding consciousness itself. Consciousness, in other words, is not given in experience as an object, but as the consciousness or awareness of an object.

While we cannot describe or define awareness, we describe and analyze the situations in which awareness occurs, and attempt to discover the laws of its occurrence and the consequences of its occurrence. Such analysis is in fact the main business of psychology, to which the analysis of content is merely contributory.

3. The "I" or *ego*, like awareness, is never an object or content. It is never anything of which one can be aware, but is given in experience as that which is aware of something else. Furthermore, the "I," as given, is nothing but that which is aware of something. Whatever else might be said in theory about the ego, is an inference (whether true or false), or a mere theoretical assumption. When we describe the ego as the soul, that is: as some-

thing having self-existence, or substantiality, or immortality, or any other characteristic beyond the mere capacity to be conscious: we are ascribing to the ego something which is not given in experience, and which, if it is to have any validity, requires demonstration by rigorous scientific procedure. For the present, at least, psychology has no concern with the ego beyond its empirically given aspect.

We may approach this point in another way by saying that there is in experience a peculiar reference or unity which is expressed verbally by the use of the letter "I". Describing experience in terms of consciousness and content does not quite sum up the complete facts. In addition to the facts which may be described by enumerating all of the details of content and all the awareness in a total experience, there remains over the fact that there is a unity, an identity, a common point of intersection. It is not true merely that there is seeing of color and hearing of sound and perception of tactual content at the present moment of my experience. Such enumeration would not differentiate between the actual case, and the case in which one person sees color, another person hears a sound and a third person has another perception. The actual fact of identity in the total experience we are attempting to describe is expressed by saying that "I see," "I hear," "I perceive" the other content: the term "I" in this statement marking or presenting the peculiar and essential identity which constitutes the organization of the experience as such. It is not far from the truth to say that in psychology we acknowledge the ego in order to ignore it in our further scientific work. Since it is not an object, and cannot be observed, there is nothing we can legitimately say about it, except, that it is that which is conscious, or, in more technical language; it is the *subject* of awareness.

4. In the experiencing of any content, bodily activity is always involved. This fact, however, is not given as a datum in the experience itself, but it is a fact at which we arrive by processes of inference and hypotheses, confirmed by experimentation. Without bodily activity of some sort there is no consciousness, and hence no experience.[6]

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[6]This statement, of course, has no bearing on questions concerning what might happen in some other world than the one which we know. With the possibility or im-

In saying that the bodily activity involved in experience is not content for that experience, we must not overlook the fact that bodily activity may in other cases be content. For example, a contraction of a muscle in my arm is observable. It is a content for my experience. But in order that I may observe this muscular content, another bodily activity must occur. This second bodily activity may again result in muscular contraction, and this second muscular contraction may also be observed, but its observation requires in turn a third bodily activity. The bodily activity essential to any single experience or connected with any single act of awareness, is not itself observable in that experience or through that awareness, but requires a second act of awareness, and hence a second experience, in order that the ego may be aware of it.

§3. Introspection and external observation.

It has long been customary to distinguish between introspection and external observation, but the actual distinctions to which this pair of terms has been applied have been various. The philosophers have constructed several different distinctions; the physiologists others; and the resulting confusion in psychology has been detrimental to scientific work.[7]

The term introspection should be used exclusively to indicate

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possibility of discarnate minds, psychology has no business. In the actual circumstances of living, the statement which we have made above holds true. What may be true in conditions other than life as we know it, is a matter of interest for religion and philosophy, not for psychology.

[7]Three of the principal theories of introspection may be mentioned. (1) That introspection is the study of the ego or I, as opposed to the study of other things. (2) That introspection is the study of awareness: the observing of observing, in a literal sense. (3) That introspection is the observation of sense data, as opposed to stimuli. To these may be added (4) the usage of the medieval philosophers who distinguished imagination and memory as *internal observation*, from sense perception as *external observation*. These four points of view are seldom found in modern psychological speculation in their pure form, but occur in various combinations with each other and with the simple view given in the text. In much of the Anglo-German psychology which has had sway until recently, it is impossible to distinguish these views clearly, an author seeming to imply now one, now another. The systems of Stout and of William James are exceptional, in that these authors adhere each to a single theory, Stout to the second, James to the first, as they are enumerated above.

The reasons for disregarding these theories of introspection are in brief (1 and 2) that no one has as yet succeeded in demonstrating that either the ego or awareness can be observed; (3) that stimuli are by their nature unobservable; and, (4) that although the distinction between imagination (and memory) and sense perception is a valid and necessary one, it is not useful to apply the term introspection in that connection.

observation of one's own body, through the visceral and somatic senses. It does not indicate simply perception of the organism as distinguished from observation of other objects, since one can, for example, see the contraction of a muscle as well as "feel" the contraction through the kinesthetic sense. In restricting the use of introspection in this way, we are but adopting explicitly a usage which has been common in experimental psychology, in spite of the varying theories which have been held. On account of the difficulty in making the term understood in the proper sense we shall avoid it in this text.

§4. The methods of psychology.

Although the name Psychology has been applied to a wide range of material, from philosophical speculation concerning the "soul" on the one hand, to the study of hypothetical "mental stuff" on the other, we shall here apply the name only to the scientific study of the mind as above described.

Since psychology is a science, it must employ the fundamental methods of all science, although it also needs to employ certain supplementary methods peculiar to its own field, just as biology, physics and chemistry each need special methods and techniques. But in every case the special methods of a science must be in accordance with and based on the general methods of all science, and cannot be in conflict therewith. It is useful to consider briefly the general principles of scientific procedure, in order that we may be able to maintain ourselves throughout on these as bases and to exclude those novelties and fads in the way of psychological theories which abandon or ignore these foundations.

The general principles controlling the development of science are five: (1) It must be primarily empirical. (2) It must proceed from its empirical starting point by the construction of working hypotheses. (3) It must subject these hypotheses to experimental test. (4) It must furnish a specific type of proof for accepted hypotheses, and, (5) It must be scrupulously exact in the use of terms.

The empirical starting point of science is its basis in indisputable facts which are *data* (that is, which are results of immediate observations), and not inferences or results of inferences. For

example: the observed fact that unsupported bodies do fall towards the surface of the earth is one of the data from which we proceed in the further acquisition of knowledge concerning the principles of gravitation and the laws of the pendulum.

Experience, from which psychology starts, is the situation in which *I am aware of something*: a situation which includes three distinct factors: *content* (something observed); *awareness* (consciousness); and *ego* (I).[8] We have seen that physical science considers only the first of these factors; but all three are data, and psychology must recognize all of them. In other words, psychology starts from the *total experience,* and not from a limited part of it.

The second point in scientific method is the construction of working hypotheses. Having observed phenomena, we seek to "explain" them: and explanation consists in the framing of hypotheses in terms of which can be described not only the phenomena observed, but other phenomena as yet inadequately explained. In some cases the hypothesis which is formed is not strictly a new one, but is an extension of an old one to a new group of phenomena. The first type of construction is exemplified by Newton's conception of the principle of gravitation, based on the observation of falling bodies: the second, by the hypothesis that the compensatory movements of the eyes (nystagmus) which follow the rotation of the head and body of an animal, are like many other reaction phenomena in that habituation to the stimulation will produce a lessening of the response.

The most significant illustration of the importance of working hypotheses in psychology is the hypothesis that consciousness is essentially dependent upon reactions. This hypothesis has been formed through observation of the cases in which bodily movements occur concomitantly with consciousness, and an extension of the relationships observed in these cases as a generalization applicable to all cases. This generalization, when made, becomes a starting point for further observations, and for experimental anal-

[8]We have emphasized the fact that neither awareness nor the ego can be described or defined. But we shall find that this characteristic of indefinability is also shared by the ultimate or primary forms of content. In fact nothing which is really ultimate can ever be defined or described, but can merely be "pointed out," by describing complex situations in which it occurs.

ysis; and when verified and accepted, it leads to the modification of other working hypotheses. When it becomes established as a fundamental principle, the whole further course of psychological inquiry is shaped and determined by it.

The primary purpose in making such a generalization as that just described is to bring as many phenomena as possible under the same principle or formulation. Having found a certain principle applicable to a specific case, we seek to find out whether or not it can be extended to cover more cases. Science always seeks to explain as wide a range of phenomena as possible by the same principle. This procedure is in accordance with the *law of parsimony,* or law of economy in hypotheses, which may be stated briefly as follows: The simplicity of a hypothesis is an indication of its truth; and of two hypotheses, the one which explains the widest range of phenomena is the truer. That is to say: if hypothesis A covers all the phenomena explained by hypothesis B, and also covers additional phenomena, hypothesis A is preferable. Again, if a single hypothesis explains phenomena which without it would require the use of two or more hypotheses, the single hypothesis is the truer. Of two hypotheses covering the same ground, the simpler is the truer. While it may seem strange that we should measure truth in such a way, it is a fact that in science we do so. The grand illustration of this fact is in the substitution of the Copernican theory for the Ptolemaic. If we should ignore the principle of economy, we should be forced to conclude that one theory is exactly as true as the other, since motion is purely relative, and hence it would be as true that the whole solar and stellar system moves daily around the earth as that the earth rotates on its axis daily. But the application of the Ptolemaic theory, with its resulting theories of epicyclic paths of the planets, and still further intricacies, is so complicated and unwieldy as compared with the Copernican that the latter is adopted, not merely as more convenient, but as *truer.*

The law of parsimony cannot be made the sole consideration in evaluating hypotheses, since a given simple hypothesis may sometimes be found to be incapable of experimental verification, while a more complex or less inclusive hypothesis may be verified. It is in the construction of hypotheses which are to be subjected to

experimental test that the law of parsimony is the efficient guide, and its observance shortens the labor of finding the ultimately verifiable hypothesis. In psychology, this principle is of the utmost importance, as we shall see in connection with later topics.

Having constructed a plausible working hypothesis, this hypothesis is not forthwith accepted as a law, but is put to the test. Further observations, and experimental tests, are made on the phenomena, for the specific purpose of finding whether the hypothesis does actually fit these phenomena.

The larger and more important hypotheses can seldom be put to experimental test as wholes, but deductions made from the hypotheses—really minor hypotheses which are necessarily true if the major hypothesis is true—are tested experimentally. If these deductions are verified by the tests, then the minor hypothesis is *so far* substantiated and is retained for further testing. If the deduction is proved false, then the hypothesis is false, and must be either reformulated or abandoned. *Experiment* is in every case the final test of a hypothesis.

Although working hypotheses may be subjected to test by mere observation, that is, the noticing of phenomena as they naturally occur, experimental tests are more vital for science, for several reasons. First, because in many cases the phenomena which it is necessary to observe do not occur unless the conditions for their occurrence are definitely arranged; or occur so seldom, or under such unfavorable conditions, that exact observation is impossible. It is possible to make a study of the effects of auditory stimulations on dreams, without experiment: but the arranging of conditions so that sleepers shall be stimulated by definite sound, or light, or other agency, at definite times, is a vastly more profitable method. Second, because observations are reliable only when the observer is prepared, at the moment of the occurrence of the total phenomenon, to observe this particular detail. Accurate observation is always the answer, *yes* or *no,* to a question which the observer has previously formulated, and this is seldom possible except in experimental work.

The value of a hypothesis depends largely on the possibility of its being tested experimentally. A hypothesis which offers many deductions which can be made the subjects of experimental

work, is valuable, even if the tests ultimately lead to its rejection, whereas a hypothesis which may possibly be valid, is of no value until it is made amenable to experimentation.

Scientific observation and experiment, if they support a hypothesis, do so through the accumulation of a type of proof which is very specific. The mere historical statement that such and such phenomena were observed, either with or without prearranged conditions, is not accepted as proof of any hypothesis. There must always be included the exact statement of the conditions under which another trained observer may observe the same phenomena. The hypothesis or deduction is not proved until these conditions are described so exactly that another person who follows these directions literally, and with no requirements laid upon him except that he shall follow the instructions as given, may obtain the results which are claimed. The nature of this scientific requirement of proof is frequently overlooked, especially by those who argue from careless observations in support of the theories of subconscious mind, telepathy and other occult phenomena.[9]

"Anecdotal" evidence, the bane of pseudo-psychology, may establish a presumption; that is, it may suggest a plausible hypothesis: but cannot serve as a means of proof of the hypothesis save in rare and exceptional cases.

The necessity of rigid definition of terms is strikingly exemplified in the history of psychology. In the physical science, careful use of terms has been the rule. Most mooted points in physics have been questions of fact only, since the same term means the same thing to both parties in the discussion. In psychology, however, the most important terms have had an unfortunate fluidity of meaning, which has led to endless confusion and has facilitated the construction of bizarre and conflicting "psychologies". "Consciousness," for example, has had at least eleven different meanings in one period; and is widely used today in three radically distinct significations. "Sensation" likewise has three quite different meanings. These two terms are sometimes used by a single author in all of their meanings, the transition from one

[9]The student may usefully compare the experimental evidence which has supported the hypothesis of radio-activity with the anecdotal evidence which pseudo-psychology offers in support of telepathy and premonitory dreams.

meaning to another resulting in grave logical fallacies and appalling confusion. Sometimes two authors who seem to agree really mean quite differently, and, conversely, many apparently vital differences of opinion are really due to a mere difference in use of terms.

In this text, terms will be used strictly as they are defined or explained. Comparison with certain other texts is difficult, because of the loose and vague use of terms in these texts. The student is especially warned that the carrying over of loose terminological usage from other texts and from popular discussion will prevent his making progress in the understanding of what is here presented.

§5. Genetic and introspectionalist psychology.

Strictly speaking, the genetic method is one of the several methods of procedure which scientific psychology may use legitimately, if sufficient care be exercised to prevent unwarranted conclusions. The method covers both child psychology and animal psychology, as we have above described them. Introspection also, as the examination of the somatic and visceral sense data and feelings, is a procedure appropriate to scientific psychology, and indeed an essential part of its method. But the terms "Genetic" and "Introspectionalist" have come to be applied to two schools of psychology which have special points of view, over and above the favoring of the two procedures which give them names, and the essential characteristics of the schools are not to be found in their use of the genetic method and the introspective procedure respectively, but in the particular way in which they use these methods.

(Introspectionalists assume that the observable world is double in form: or, we may say, that there are two objective worlds. One of these is the physical world: the other a quite distinct psychical world. Between these two worlds there is supposed to be a *correspondence* such that for each object in the psychical world, there is an object, or complex of objects in the physical world. Both, however, are assumed to be directly observable and to resemble each other so much that it is quite possible, when attempting to observe psychical objects, to observe physical facts instead.) This confusion is not only assumed to be possible, but to actually oc-

cur, even in the observations of psychologists who do not work on the introspectionalist assumptions. This alleged confusion is called the "stimulus error": the stimulus, on this hypothesis, being the physical object which corresponds to the psychical object.

For the introspectionalist, therefore, psychology consists in the observation of the psychical objects, just as physical science consists in the observation of the physical objects. As to the exact distinctions and relations between these two classes of objects, introspectionalists are not in complete agreement. In the examination of the spectrum, for example, some introspectionalists say that the actual colors observed are the same, whether examined by the psychologist, for psychological purposes, or by the physicist for physical purposes, introspection and external observation being then identical for this case. Other introspectionalists, however, insist that even in this case the objects examined are different.

The metaphysical conceptions of the introspectionalists need not concern us directly, for in many cases the actual results of their observations are precisely the same, when reduced to practical form, as the results of observations of psychologists who proceed empirically. The conceptions do, however, seem to have an influence on the introspectionalist's further methods, which distinguishes these methods from those methods which we have above described as scientific. The introspectionalist, when observing, tends to attempt the observation of all possible content occurring during the period of observation, instead of limiting himself narrowly to definite details which the observer may plan in advance to observe. Masses of reports on visceral and somatic data, thought-content, and content of external perception are thus obtained: information which is often picturesque, and which illustrates the complexity and massiveness of total content at any one time, and the great individual differences in attention and discrimination; but from which, in general, definite conclusions cannot be drawn. The study of such introspective reports strongly enforces our conclusion that empirical basis and scientific method are of the utmost importance for psychology.[10]

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[10] For the clearest statement of the introspectionalist assumptions, see Boring, *The Stimulus Error, American Journal of Psychology*, Vol. 32, 449-471. For characteristic introspective reports, see Hoisington, Vol. 31, 114-146: Sulivan, Vol. 32, 54-80; O'Brien, Vol. 32, 249-283; and many other authors in the same journal.

The genetic psychologists usually start from an introspectionalist basis, and attempt to trace the development of the world of mental objects, in some such way as the biologists trace the development of the particular class of physical objects called living organisms. Here, again, a general procedure into which many members of the school commonly fall, is not essential to the fundamental method, but is nevertheless characteristic of the school. This procedure consists in the uncritical ascription to the young or lower animal of mental processes occurring in the adult human animal. The observer finds in the child certain actions which accompany certain mental processes in the adult, and naïvely concludes that the child has such and such processes: without knowing whether the actions which he construes as signs are accidental or essential accompaniments or whether they may not be equally signs of two or more quite different processes. The genetic psychologist is such, in typical cases, because he is impatient with the slow progress in the study of the adult human mind, and proposes to study, in some more direct way, the lower forms of mind, unhampered by critical evaluation of the relationships between conscious processes and external signs in the adult. In most cases, however, the genetic psychologist's impatience with adult human psychology arises from the fact that he envisages the latter in the introspectionalist form, not in the form which we have called scientific. In the latest, or "behavioristic" form, the tendencies of this school become most explicit. Reactions of infants are interpreted in terms of the conscious reactions of adults, but the discussion of the grounds for such interpretation is explicitly excluded. Certain genetic psychologists, for example, having observed in the young infant reactions which in the adult may be indicative of either fear or of pain experience, call the infant's reaction "fear," and make subsequent inferences as to the appearance and development of the "fear instinct", which would not be made if the observed reaction were described as "pain".

Many psychologists, who are not to be classed with the genetic school, use the basal genetic method extensively, and with cau-

tion.[11] These psychologists are often loosely classed with the genetic school, but a clear distinction should be made here, just as is done in the case of psychologists who employ introspection (in the scientific sense) but are not introspectionalists.

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[11]For illustration of the methods of the genetic school, we may refer to J. Mark Baldwin, *Mental Development*, and John B. Watson, *Psychology*. Judd, *Psychology*, emphasizes the genetic method, but is not here classed as belonging to the genetic school.

CHAPTER II

SENSE PERCEPTION

§1. Complex and elementary sense objects.

Sense objects, or sense data, as perceived, are usually complex, that is: they are made up of two or more simpler sense data, combined in various ways. Sometimes these data are presented as occupying different spatial positions, as is the case with the black and white of the printed page. These combinations are mere conjunctions. Sometimes, however, the several data combined in the total object occupy the same space, or are localized in the same position, as is the case with the purple of a purple aster, and the coldness, touch characteristics, and whiteness of snow. Such combinations are commonly called *fusions*. It is useful sometimes to distinguish between fusions of data of the same mode, such as red and blue, and fusions of data of different modes, such as red and warm, cold and pressure. The latter combinations are conventionally called *complications*.[12]

The analysis of conjunctions and complications offers no especial difficulty in most cases. In the case of the snow, we readily observe that its total perceptible nature includes both whiteness and coldness, but that they are separable factors. Still more easily analyzable are combinations of color presented as adjacent to each other. In the case of fusions in the same mode, analysis is more difficult, requiring especially keen observation, and in some cases leading to results which have become matters of dispute. While all careful students agree to a separation of cold and warmth from the touch, tickle and pain factors with which they are fused, there has been controversy over the analysis of fused colors, as in the cases of purple (red and blue), and orange (red and yellow).[13]

The analysis of complex objects may be carried to such a point

[12]Warren calls them colligations.

[13]Orange is here described as a combination of red and yellow, in accordance with popular usage. Strictly, however, yellow is a combination of red and chlor (greenish yellow), and orange is a combination of the same pair, with a higher proportion of red.

that we obtain factors which resist any further analysis. Such factors, for example, are redness, sweetness, and the cutaneous pain which results from sticking a needle into the skin of the hand. None of these can be dissected by any means, or broken up into other factors. These ultimate results of analysis are called *simple sense data.* For conciseness sake, however, we shall refer to them as *sentienda* (singular, *sentiendum*).[14]

Sentienda are apparently fused in three different ways: First, into complexes in which each of the elementary sentienda are recognizable, as in purple, the sweet-sour of lemonade, and the cold-pressure of the handful of snow. Second, in complexes in which one or all of the component sentienda are unrecognizable for ordinary observation, although the complex itself is observable. For example, white, an observable datum, is a fusion of red, blue and a certain other color (sometimes called yellow and sometimes called green, although as a matter of fact it is neither). Yet in the white, none of these sentienda can be directly observed. Again, we may add a little blue to a pure red and so change the total hue that the fusion is recognizably different from red, although the blue component cannot be distinguished.[15] Third, we may combine two odors, such as iodoform and balsam of Peru, in such a way that not only is neither odor observable, but not even the combination is perceptible. In such cases the result may be due to the actual destruction of one sentiendum by another. Two beams of light, for example, may be superposed in such a way that darkness is produced. It may be true, however, in certain other cases, that the product of the fusion of two sentienda actually exists although it cannot be perceived. This is a speculative point which has no present interest for us.

[14]Sentienda have been called "sensations," "simple sensations," and "pure sensations," by the Anglo-German psychology. Sensation, however, has several other significations in that psychology, and hence, to avoid the confusion which has become a serious matter, we shall not use the term at all. Sentienda might be called *simple sense objects,* were it not that the current confusions between consciousness and sense-data, and between sense data and physical stimuli make this usage incomprehensible to some readers.

[15]While this statement holds true for certain observers, it may be that everyone, with sufficient training, can learn to distinguish the relative blueness of the one color. In the case of white, the statement holds without qualification.

§2. The characters of sense data.

All sentienda possess four intrinsic characters, namely: *quality, intensity, extensity* and *duration* (sometimes called *protensity*). These characters are not components or elements in the sentiendum: the sentiendum can by no means be analyzed into them. They are merely aspects or points of view from which the sentiendum may be considered. Perhaps the best way in which to describe the characters is to say that they are ways in which sentienda may differ from one another. For example: two spots of red may differ from each other in three ways: one may be a bigger spot than the other; this is a difference in extensity. One spot may be brighter than the other;[16] a difference in intensity. One spot may last longer than the other; a difference in duration. Yet the the two spots may be *both the same* as regards redness itself.

Between a red spot and a blue spot these three differences (in intensity, extensity and duration) may obtain just as they do between two spots of red, and there is also the fourth difference, in quality, which is exactly illustrated by the difference between red and blue, regardless of the other characters. This qualitative difference, in short, may be present although there may be no difference whatever in intensity, extensity and duration.

In addition to the intrinsic characters, there are two others, namely: position in time and position in space; which may for convenience be designated as extrinsic. Sentienda (and also complex data) may differ in regard to the time at which they occur, and the place in which they exist. In the case of the fusion of two sentienda, neither can differ from the other in temporal and spatial position; but the two together differ alike in these respects from other sentienda.

No sentiendum can be existent if it has not all six of these characters. In other words: a sentiendum which has no quality, or which has no intensity or no extensity or no duration, or which does not exist at some particular time, or which does not exist in some particular place, is a pure fiction. Two particular sentienda may, however, differ in only one of these characters. Two spots

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[16]Unfortunately the term "brightness" has been applied by some authors to what is more popularly called *saturation*, namely, the amount of white mixed with a predominatingly single color. We shall, however, throughout use intensity in its original signification of color intensity.

of red, for example, may be alike in quality, intensity, extensity, duration and temporal position, differing only in spatial position. Any two sentienda, however must always differ in at least one character: otherwise, there will be not two, but only one.

§3. The senses.

The total range of conscious responses to sense data is customarily divided into several groups called senses. Although the division is fundamentally a division of responses rather than of sense data, nevertheless the responses are grouped primarily with reference to the qualitative differences in the sense data themselves, rather than with reference to the physiological mechanism. As might be expected, however, we find ultimately that the differences in the sense data do correspond to differences in the details of reaction.

The senses as thus distinguished have been known since Helmholtz's time as *modes of sense,* or more conveniently as *modal senses.* This characterization is necessary in order to distinguish this division of sensitivity and of sense objects from another division which results in the groups known as the *regional senses.*

Popularly, there are supposed to be five senses: sight, hearing, taste, smell and touch. Actually, the number is greater: a tolerably complete list of the modal senses distinguished in accordance with the sense data includes at least fifteen. These modal senses are listed in the table on page 42, along with certain technical terms which are currently applied to sensory details. In the first column are given the common English names of the senses. In the second column, the more technical names derived from the Greek or Latin. Those terms in this and other columns which are legitimate, but not in wide usage, are enclosed in parentheses. In the third column are given the terms for the absence of sensitivity, that is: for the absence of response to the data of the given sense. The fourth column includes adjectives applying to the sensitivity and to the sense data.

Concerning the senses of taste, smell, sight, hearing, touch, warmth, cold, pain and movement, there is no question. These are all separate senses, and are so recognized by psychologists and physiologists. The pressure sense, tickle sense and vibration sense are confused often with touch by those who have given little at-

tention to the data of these senses, and to the reactions involved in their functioning. The distinctness of these senses, however, is well substantiated. The fatigue sense has not been recognized generally, but extended observation of one's bodily sense data reveals data of "weariness" which cannot be ascribed to any of the other modal senses in the list. The only senses listed which are really questionable are the sexual and vertigo senses. The first may be reducible to protopathic pressure and certain other subcutaneous senses as yet unanalyzed. In any case, it is restricted, topographically, to small areas of the sex organs, and is not to be confused with the sexual emotions resulting from stimulation of these areas. The data of the vertigo sense may turn out to be complexes of several visceral modes, but both of these senses must be listed provisionally.

Complete analysis of the sensitivity of the visceral organs will undoubtedly reveal additional modal senses, which for the present must be slighted in our treatment.

Some of the senses have sense objects of one quality only. Others, as for instance vision, have objects of different qualities. In speaking of the qualitative differences between objects of different senses (as, for example, the difference between red and sweet), the terms *mode* and *modal* are substituted for the terms quality and qualitative, the latter terms being specifically applied to differences within the senses: as, for example, the difference between red and blue, and the difference between sweet and sour.

For purposes of convenience, the total range of sensory responses is further classified by reference to the region of the body directly affected by the stimuli, without reference to modal differences. The groups thus obtained are designated as *regional senses*. The two principles of classification are sometimes confused.

Reference to the dermal sense, hair sense (trichoesthesis), muscular sense (myoesthesis), joint sense, retinal sense (vision), cochlear sense (audition), vascular sense, genital sense, gastric sense, and gullet sense, are to be understood in the regional way. A convenient quasi-regional division of all the senses into four groups: cranial, somatic, visceral, and labyrinthine, is sometimes made. The cranial group includes vision, audition, olfaction and gusta-

tion only, the labyrinthine sense being excluded. The somatic senses include the dermal senses, kinesthesis, trichesthesis, and palmesthesis. The labyrinthine sense includes the sensory function (if any) of the semicircular canals and vestibule of the ear only, although the cochlea is also a part of the "labyrinth." The sexual sense is included in the visceral group, rather than the somatic.

TABLE OF THE MODAL SENSES

I	II	III	IV
Taste	Gustation (Geusis)	Ageusia	Gustatory Geusic
Smell	Olfaction (Osmesis) Osphresis	Anosmia (Anosphresia)	Olfactory (Osmetic) Osphretic
Sight	Vision (Opsis)	Anopsia	Visual Optic Optical
Hearing	Audition (Acusis)	Anacusia	Auditory Acoustic Acoustical
Touch	Tact (ion)	Anaphia	Tactual Haptic
Pressure Sense	Baresthesis	(Baranesthesia)	Baresthetic
Warmth Sense	(Thalposis)	(Athalposia)	(Thalpotic)
Cold Sense	(Rhigosis)	(Arrhigosia)	(Rhigotic)
Tickle Sense	(Gargalesthesis)	(Gargalanesthesia)	(Gargalesthetic)
Vibration Sense	Palmesthesis	Palmanesthesia	Palmesthetic
Pain Sense	Algesis	Analgesia	Algetic Algesic
Vertigo Sense			Vertiginous
Movement Sense	Kinesthesis	Akinesthesia	Kinesthetic
Sexual Sense			Voluptual
Fatigue Sense			

Another regional division of the senses classifies them as, *exteroceptive, interoceptive* and *proprioceptive,* and distinguishes the receptors of these as exteroceptors, interoceptors and proprioceptors respectively. The exteroceptive senses include the modal senses of vision, audition and olfaction, and the regional dermal

senses. The interoceptive senses include gustation and those divisions of the other senses (tactual, thermal, algetic and gargalesthetic) which are regionally restricted to the inner surface of the alimentary canal (mouth, gullet, stomach, intestines and anus). All other sensory mechanisms, namely, those regionally distributed between the inner surface of the alimentary canal and the external surface of the body, are included under the heading of proprioceptive. This classification, although doubtless very useful for physiology, does not lend itself to psychological use.

§4. Sensory stimuli.

In the scheme of the physical sciences, sensory objects or sense data, which constitute a fundamental part of the perceptible world, are represented by *stimuli.* If we should discuss adequately the relations of physical stimuli and sense data, we would necessarily enter one of the most abstruse fieldsof metaphysics.[17] For our purpose, we must consider only the empirical facts in connection with the complex problem. First: physical stimuli, as they are scientifically conceived, cannot be perceived through the senses. They are not sense data: they lack the fundamental character of quality. A stimulus to the eye (ether vibrations), cannot be seen: a stimulus to the ear (periodic movements of air molecules), cannot be heard: and so through the whole series of stimuli. Secondly: so far as our knowledge goes, physical stimuli are mathematical expressions and nothing more. In other words, they are expressions, in terms of mathematical conventions, of the complex relations and systems of relations subsisting between sense data. One might suppose, of course, physical stimuli to be something more than this, although one would have difficulty in stating that supposition intelligibly; but such suppositions can be neither proved nor disproved by scientific methods, and belong to the realms of philosophy and religion, lying quite outside the sphere of interest of science.

The mathematical conception of physical stimuli is of great assistance, since we can thereby sum up in a few words or in pic-

[17]It is customary to rush into this metaphysical field (that of epistemology) by making the assumption that physical stimuli are real, substantial objects, and that the perceptible data are somehow derived from these. Following the empirical method, we must refrain from such speculative conclusions. Conclusions in this field can be reached only through a long and rigid course of epistemological research.

torial expressions, a vast array of relations. We need use the term physical stimulus in this way only, although if any one chooses to believe that a physical stimulus is a divine force, a mystic energy, or something equally abstruse, he may prevent such belief from having a bearing on his psychological work.

The term *stimulus,* however, does not, in current usage, always mean physical stimulus. In a looser, but customary, way of speaking, we apply the term to a simple or complex sense object of which the physical stimulus is the mathematical expression. Thus, we may speak of an orange as a stimulus to the sense of vision, meaning thereby the object perceived, and not the mathematically conceived ether-vibrations. In further discussions in which sense-data are referred to as "stimuli", the expression "mathematical expressions corresponding to" is to be understood as qualifying the references to sense data, if the term stimuli is taken in a strict sense. Stimuli of this type may be designated as *unresolved: i. e.,* not reduced to physical stimuli.

Stimuli are further divided into two general classes: *adequate* and *inadequate.* These terms are unfortunate, but are in good usage. They should be understood to signify merely *usual* and *unusual* stimuli respectively.

We can usefully list stimuli in three classes: of which the first includes stimuli which are both adequate and physical; the second includes adequate stimuli in the looser, unphysical sense, and the third, Class III, includes inadequate stimuli, both physical and unresolved.

Class I. Physical Stimuli

(1) Ether vibrations: periodic movements of the hypothetical ether, which is conceived as pervading space and objects in space. Light, physically considered, consists of ether vibrations of a determinate range of periods, which affect the receptors in the retina of the eye. Ether vibrations of certain other periods do not affect the visual receptors, but affect receptors in the skin and other tissues, giving rise to perception of warmth and cold. When for example, you hold your hand near a fire and perceive the warmth, the ether vibrations radiating from the flame reach the skin and produce their effects there.

(2) Molecular vibrations. When a piece of hot metal or a piece of ice is applied directly to the skin, it is possible that the molecular movements of the metal are communicated directly to the molecules in the skin, and that the molecular movements in the skin are communicated directly to the molecules of the ice.

(3) Molar vibrations. In these cases, molecules making up a physical substance actually change their position in space periodically. This form of vibration, which is sometimes called molar vibration, therefore differs from the molecular vibration in which the molecules are supposed to vibrate without necessarily changing their positions. Molar vibration of air is the usual stimulus for the auditory mechanism; but molar vibration or oscillation of the molecules of the bones of the head, as in the case where the stem of a vibrating tuning fork is pressed against the head, may also serve as auditory stimuli. Molar vibrations transmitted to the skin and sub-cutaneous tissue, and to the bones, are stimuli of the vibration sense (palmesthesis). Such, for example, are the vibrations received when the hand is placed on the wood of a violin which is being played; or when a vibrating tuning fork is touched by the hand.

(4) Chemical stimuli. The activity of various chemical substances stimulates certain sensory mechanisms in the organism. This action may be similar to that described under (1), (2), or (3) above; but for the present, it is best to allow for a separate group of chemical stimuli. The stimuli for the senses of taste and smell belong to this group.

Class II. Stimuli As Yet Unresolved

(1) Conditions of the tissues. Such conditions as of thirst, which is due to dryness of the soft palate and of the upper part of the gullet, and various perceptible conditions of the alimentary canal and other tissues, may possibly be referable eventually to the preceding class of chemical stimuli. Such reference at present would be premature. It is well to make a separate class of these unresolved stimuli.

(2) Light moving contact. This type of stimulus is exemplified in the brushing of the skin with cotton wool, which produces tickle. It is characterized by the surprisingly slight amount

of energy required to produce a powerful reaction, as compared with stimuli of the other dermal senses.

(3) Movement of joint surfaces over each other. In the bending of the elbow, for instance, the movement of apposed joint surfaces stimulates the nerve endings and gives rise to the perception of movement.

(4) Deformation of tissues. This form of stimulus may be illustrated by pressing on the skin, so that its level is altered, or by pulling on a hair with a corresponding result. In other cases, certain portions of the skin or sub-cutaneous tissues have the pressure exerted upon them changed, or the actual form of the tissues modified by movement of the members which the skin covers. Striking or pressing on a tendon may produce stimulation of nerve cells ending in the tendon.

(5) Muscular activity. In addition to the deformation of the skin and other tissues which lie above the muscles, the contraction or relaxation of muscle in some way stimulates receptors which terminate within the muscles themselves, giving rise, in some cases, to the perception of movement or of contraction. The exact physical nature of the stimulation process is unknown, but the results are demonstrable. In the case of the visceral muscles, also, contraction and relaxation are effective stimuli.

(6) Acceleration of movement. When the movement of the body as a whole is accelerated or retarded, stimulations of various receptors in the body are produced. These stimulations are probably all matters of pressure or deformation, due to the inertia of the body or of parts of the body. In the rotation of the body about any axis, similar stimuli occur; and in rotary movements of the head without the body, stimulation of the sensory mechanism in the semi-circular canals is produced.

(7) Absence of customary stimulation. In some cases, cessation of action of a stimulus seems actually to stimulate the sensory mechanism. Thus the removal of light stimulus from the eye is supposed to be the cause of the perception of black, and the removal of sound stimulus from the ear the cause of the perception of silence; and neither of these can be accounted for in direct terms of the positive stimuli of the visual and auditory mechanisms.

Class III. Inadequate Stimuli

Inadequate stimuli can be conveniently classified under five headings. In this list, (1) and (3) are strictly physical.

(1) Electricity. Almost any of the sensory mechanisms can be stimulated by application of electric current, and in some cases, by the application of a magnetic field. Electric current applied to the tongue will produce taste perception; applied to the eye, visual perception; applied to the skin, touch or other dermal perceptions. If the head be surrounded by a coil of wire through which alternating current of sufficient amperage and sufficiently slow frequency is passed, a brilliant flickering of light will be perceived.

(2) Pressure. Some of the sensory mechanisms which are normally not stimulated by pressure may nevertheless respond to this form of stimulation. Thus, pressing on the eye ball in certain ways will produce an experience of light.

(3) Chemical. In certain cases, the application of chemical substances will produce the effects of adequate stimuli of other kinds. Thus, peppermint or menthol may produce the experience of cold in the mouth; red pepper and alcohol the experience of heat.

(4) Mechanical injury. Cutting or bruising of receptor cells, or of afferent nerve fibers, will produce pain.

(5) Conditions of the tissue. Pathological conditions of the tissues may stimulate various sensory mechanisms in ways which are at present unknown. Thus, in inflammation of the skin, heat may be experienced.

This is not a complete list of inadequate stimuli but merely an illustrative one, including the commonest stimuli which may be classed as abnormal or unusual.

§5. The physiological sensory mechanism.

Sense perception involves response or reaction of the mechanism to some stimulation. The ultimate or final part of a response consists in the activities of *effectors*—muscle cells and gland cells—or the inhibition of their activities. Muscle cells act by contracting and relaxing; gland cells by secreting, that is, by manufacturing and delivering certain solutions, such as saliva and bile, which are of use to the organism, or urine, which is a waste product.

The effector activities are set up by *efferent* current, which is discharged to these effectors from the brain stem or from the spinal cord through efferent nerves. In general, such efferent discharges result from preceding afferent nerve currents which are conducted into the spinal cord or brain stem over the afferent nerves, and which originate in receptors, these receptors having been stimulated either by external objects or by processes in the body itself. It is possible that certain efferent discharges occur as a result merely of chemical processes (such as stimulation by carbon dioxide) in the cord and brain stem without the causal effect of previous afferent currents. Such efferent discharges, if they do occur, are, however, modified and otherwise controlled by afferent current, and hence become components in the more general reaction processes.

If we examine the details of reaction processes in the way in which they occur, we find:

(1) stimulation of receptors.

(2) conduction of nerve current into the cord and brain stem (afferent current).

(3) central nervous processes, consisting mainly of transfer of current from point to point within the central division of the nervous system (including the spinal cord, brain stem, cerebral hemispheres and cerebellum.

(4) conduction of current outward from the cord or brain stem (efferent current) to the muscles or glands or both.

(5) contraction or relaxation of muscle cells, and secretion or inhibition of secretion of gland cells. This constitutes the "action" phase of the reaction.

A more extended treatment of the reaction process must be deferred to a later point; at present we are concerned merely with the initiation of the reaction process by stimulation of receptors.

Receptors are cells: all of them are of microscopic diameter, and some are entirely microscopic, while others are of considerable length. In order to produce sense perception, stimulation must always be applied to some portion of the body in which lie receptors capable of responding to that particular kind of stimulation, or in which such receptors have their external (peripheral) termination. In all the senses except vision, audition and gustation, the

receptors are relatively long nerve cells, and have their external terminations in the tissues (skin, mucous membrane, muscles and tendons, subcutaneous tissues, and viscera) to which stimulation must be applied; and the other terminations are central (that is, in the spinal cord or brain). The receptors of vision are microscopically short nerve cells, lying within the retina of the eye. The receptors for gustation and audition are epithelial cells lying wholly in the mucous membrane of the mouth and tongue and in the basilar membrane of the inner ear respectively. In these cases, the receptors are connected with the brain-stem through a nerve cell or series of nerve cells.

Each sort of receptor is specialized to respond to a single type of stimulation, or to a single group of stimuli, and correspondingly, the reactions to which they give rise involve the perception of a single sentiendum or small group of sentienda. The receptors in the retina, for example, function for color only (including gray); the receptors of the cochlea for sound only.

CHAPTER III

THE CRANIAL SENSES

§1. Gustation.

Gustatory sense-data are usually called *tastes*. We speak of the "taste" of food or drink; of a "sweet taste", a "bitter taste", a "metallic taste", etc. The elementary tastes, simple gustatory data, or *gustatory sentienda,* are of four qualities only: sweet, salt, bitter and sour. All other tastes, that is, all tastes having qualities other than one of these, are fusions of two or more of these elementary tastes. Bitter sweets, sour salts and bitter sours are more familiar than salt sweets, salt sours and salt bitters, although all of these fusions are possible. Fusions of three of the simple tastes also occur; for example, the sweet-bitter-sour of ripe grapefruit is well known.

The gustatory data also fuse with tactual and dermal data and with olfactory data to produce flavors. In all the varieties of flavors of foods and drinks only the four taste qualities occur, the other components in the flavor—frequently the most important components—being odors, warmth, cold and touch.

The qualitative relationships of the four gustatory sentienda to each other and also the possibilities of fusion are represented by the taste tetrahedron in Fig. 1.[18]

In this figure, representing a solid or three dimensional scheme, each of the four elementary tastes is represented at one of the four vertices of the tetrahedron. The lines joining these points represent the fusions of the simple tastes in pairs. For example, points along the line joining sweet (Sw) and bitter (B) represent fusions of these two in varying proportions, from the slightly sweetish bitter, through a balanced proportion, to a slightly bitterish sweet. Mixtures of three of the sentienda; for example, sweet, bitter and sour, would be represented by points in the surface determined by

[18]Intensity relationships are not included, as a four-dimensional scheme would be required for this purpose.

the position of these three simple qualities. Fusions of four can be represented by points lying within the solid figure.[19]

The receptors for taste are found on the upper surface of the tongue and the edges of the tongue, the surface of the soft palate, and even over certain parts of the lining of the pharynx and larynx. The central portion of the tongue surface is usually devoid of receptors. In young children and occasionally in adults, receptors occur also in the mucous lining of the cheeks, the surface of the gums, and even the lips.

The stimulus for taste is chemical. Substances which are sapid, that is, which have taste, must be soluble in water. Substances

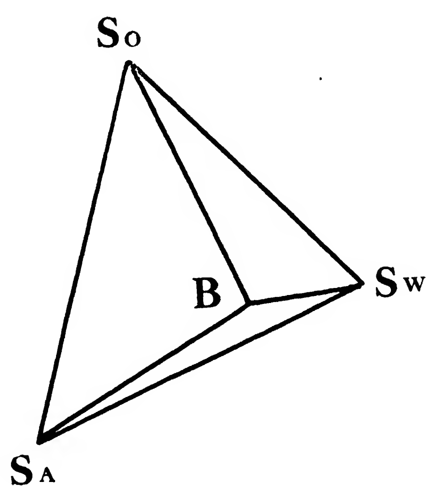

Fig. 1.—Taste tetrahedron. The four points, B, So, Sw, and Sa represent the four elementary taste qualities; and points on the lines joining these represent binary combinations of these qualities. Mixtures of three of the qualities are represented by points lying in the surfaces of the tetrahedron, and combinations of four, by points lying within the tetrahedron.

which are not soluble are incapable of exciting taste perception, although not all water soluble substances are sapid.

In obtaining actual fusions of the four simple tastes by mixing substances which stimulate two or more of these, we must use substances which will not chemically combine in solution to form new substances, since such chemical combinations essentially

[19]Attempts at representations of qualitative taste-relations have been attempted by means of a plane figure. Such schemes are erroneous, since they necessarily represent the combination of one pair of tastes as equivalent to a combination of the other pair, which is not true.

modify the stimuli. By mixing solutions of table salt, cane-sugar, hydrochloric acid and quinine chlorid, satisfactory results can be obtained.

In making such mixtures, it is found sometimes that the intensity of a fused taste is less than the intensity of each of its components. This reduction in intensity is especially characteristic of fusions of sweet and salt. A very weak salt added to a very weak sweet may result in approximate tastelessness. A mixture of sweet and strong salt gives a definite alkaline taste, but this alkaline taste may be much less intense than the salt and sweet from which it is blended. In mixing sweet and sour, intensities are sometimes reduced, sometimes not.

Adaptation effects are sometimes noticeable in gustation. A sour solution, such as one of lemon juice for example, often seems sourer after the mouth has been filled with something sweet. (This is described as *contrast effect.*) Continued stimulation with sweet, as in sipping a strong syrup, results in an apparent decrease in the sweetness of the solution, that is, in a decrease in sensitivity to the stimulation.

These adaptation effects are exceedingly variable and the strength of the stimulus seems to be the most important factor. The phenomena are sometimes absent and sometimes reversed. Sometimes the stimulation of one quality will decrease sensitivity to one or more of the others. Where contrast is present, stimulation of one simple taste may heighten the sensitivity for sometimes one, sometimes another of the remaining three. Contrast effects are less apt to appear in respect to bitter than to any of the other three tastes.

Certain substances affect the sensitivity of the taste receptors without themselves having distinct tastes. The leaves of gymnema sylvestris, when chewed, dull the sensitivity to sweet and bitter, dulling sweet especially, without affecting sensitivity to salt and sour. The leaves of the yerba santa of the Pacific Coast, on the other hand, increase the sensitivity to sweet. These effects are, of course, temporary. It has been alleged that tobacco smoking diminishes the sensitivity to sweet through its effects on the tip of the tongue, in which location receptors for sweet are relatively most numerous.

§2. Olfaction.

Olfactory sense data are commonly and properly called *odors.* While it is possible that there are elementary odors (*olfactory sentienda*) comparable to the four simple tastes, none such have been discovered. Attempts have been made to classify the vast range of discriminable odors into a small number of groups, but such classification has little practical value.[20]

The receptors for odor lie in a restricted area (the olfactory membrane) in the upper part of the nasal cavities. The stimuli are chemical substances in a gaseous form, *i. e.*, dissolved in air. Mere floating particles of matter, that is, dust particles, although they may be borne by the air into the nasal passages, are not odorous unless the particles give off gaseous emanations. In the act of smelling, we sometimes "sniff" by narrowing the *anterior nares* (external openings of the nostrils), and inspiring more forcibly than in ordinary breathing, so that the air-currents which carry stimuli are directed upwards into the region of the olfactory membrane, and thus we secure maximally favorable conditions of stimulation. Under conditions of ordinary respiration, the osphretic substances are diffused upwards from the air currents which pass

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[20]The classification most commonly referred to is that of "Linnaeus" (the name by which the Swedish botanist, Carl von Linné, 1707-1778, is commonly known), which is here given, with examples of the several classes:

1. Aromatic—Turpentine; lavendar; camphor; spices; butyric ether.
2. Fragrant—Flowers; vanilla; benzoin.
3. Ambrosiac—Musk; ambergris.
4. Alliaceous—Garlic; assafoetida; Cl.; Br.; CS_2.
5. Hircine—Cheese; sweat; rancid oil; lactic acid.
6. Repulsive or Virulent—Opium; nightshade family.
7. Nauseous—Decaying animal matter.

To this list the Dutch physiologist Zwaardemaker, in his book *Die Physiologie des Gesuchs*, in 1895, added two others:

a. Ethereal—Fruits; some essential oils and ethers.
b. Empyreumatic—Toast; tobacco smoke; tar; coffee; gasolene; creosote.

A more recent (1916) form of the traditional list, constructed by a German physiologist, Henning, reduces it to six—flowery, fruity, putrid, spicy, burning and resinous.

Classificatory work of this kind does not seem a promising method. Henning thinks the work of his predecessors was futile, and the next classifier will probably think the same of Henning's labors.

A more promising type of classificatory work was introduced by Sir William Ramsay, who found that there are resemblances of odors of organic substances belonging to certain chemical groups. This work has been continued by Haycraft and others, but as yet no sweeping principles of classification have been discovered. We may reasonably expect, however, that sometime, definite relations between types of odors and types of chemical structures will be discovered.

through the nasal cavities from the anterior nares to the *posterior nares* (the openings of the nasal cavities into the pharynx). Even when the breath is "held," or when breathing is entirely through the mouth, stimuli may be diffused into the nasal cavities through the anterior and posterior nares, and produce their effects.

The *flavors* of foods and drinks are, as has been stated previously, composed largely of odors. This may be demonstrated in a conclusive way by stopping both the anterior and posterior nares, whereupon all flavors are reduced to somewhat uninteresting combinations of salt, sweet, bitter, sour, warmth, cold and tactual sense-data. Tea, coffee and quinine solution cannot be distinguished from one another under these conditions, and the residual flavor of any fruit juice can be imitated by a proper mixture of water, sugar and acid (*e. g.*, vinegar), with quinine added for such fruits as shaddock, and an astringent, such as alum, added for pineapple. The various meats are indistinguishable; and vegetables can be discriminated from each other with great difficulty only by means of their tactual "feel" or coarseness and their resistance to mashing or chewing. If cooked and mashed to an equally pulpy condition, all vegetables taste alike when the olfactory stimulation is excluded.

Stopping the anterior nares alone is sufficient to bring about the loss of odor with consequent impoverishment and confusion of flavors, if care is exercised in breathing, so that odors are diffused as little as possible into the nasal cavities through the posterior nares. Nasal "colds," involving swelling of the mucous membranes sufficient to obstruct the nasal passages, often produce these results in marked degree.

Mixtures of odors produce results varying widely according to conditions. Sometimes there is obtained an apparent fusion in which the original odors can still be discriminated. Sometimes an entirely new odor is produced. In some cases, the intensity of the mixture of two odors is so low, as compared with intensities of the odors independently, that the two are said to be *compensatory*, or to *cancel* each other. In other cases, one odor will "drown out" another, so that the second is not distinguishable, but the first odor is perceived as if the second were not present. Various aromatic

odors, such as the odors of burning substances, or of creosote, are frequently employed to mask or cover unpleasant smells.

Adaptation is a striking feature of olfaction. Most osphretic substances, if present continuously for some time, become imperceptible. If the reactor is in a closed room in which there are fragrant flowers, or a slight amount of illuminating gas, after a time he will not perceive the odor. Then if he goes out into pure air for some minutes, and subsequently returns to the room, he at once notices the odor. Similarly, on entering a crowded auditorium, the effluvia of the people present may be almost unendurable, at first, but later become unnoticeable. One unfortunate result of olfactory adaptation is that we may subject ourselves to noxious gases unknowingly. Another result is that persons with strong body odors may not be aware of those characteristics, although other persons in their vicinity may perceive such odors distinctly.

Adaptation is sometimes described as *fatigue* or *exhaustion,* but these terms do not seem to be accurately applied. The adaptation seems to be rather of a protective sort: the receptors in some way become shielded from the effects of the stimulus, and cease to respond: a condition which is more like the wetting of the powder in a fuse, rather than its being burned out completely, although in either case the fuse refuses to burn. This conception, at any rate, is in harmony with the protective and immunizing processes which are found in connection with various organic functions.

Adaptation to one odor may carry with it adaptation to certain other odors. It has been proposed to make use of this peculiarity of odors to discover the essential relationships of olfactory sense-data, and perhaps to arrive at the elementary odors. So far, however, the total results of such investigations have not been of great importance.

Anosmia or *anosphresia:* the permanent and complete absence of the sense of smell, has been found in many individuals. It is generally accepted that there is a hereditary type of anosmia, and the occurrence of total anosmia in several successive generations of certain families bears out the supposition. In other instances, disease of the nervous system has produced the defect. A congenitally anosmic person can never know what he misses in the world of odors and flavors. While his loss is not so practically important as

is that of the totally blind man it is actually far greater in respect to the number of qualitatively different data which are imperceptible to him.

Partial anosmia, or *parosphresia* is of frequent occurrence. This may take the form of, (1) an entire lack of sensitivity for certain odors, although other odors are normally perceived; or it may take the form of, (2) a general weakening of sensitivity to practically all odors. As compared with the keen sensitivity of certain individuals, a large percentage—probably the majority—of the human race would be rated as partially anosmic.

§3. Vision.

The data of vision are properly called *colors* or *hues,* and *gray.* There are currently assumed to be elementary colors *(visual sentienda),* and all other colors are fusions of two of these in different proportions, and at different intensities. Gray is a fusion of all three visual sentienda in such proportion that no one of them is visible as such in the complex.[21]

Two of the three visual sentienda are commonly called *red* and *blue.* The third is sometimes called "yellow" and sometimes "green," the variation in naming being due to the fact that it is really neither of the colors usually designated by these two names, but is, in common terminology, a *greenish yellow.* For this color, the term *chlor*[22] has been suggested, and will be used throughout our discussion.

We must bear in mind that color names were fixed in European languages long before any analysis into elementary colors was made, and that the common names had their origin in practical considerations. Important natural objects such as the sky, grass, trees and gold were described, and simple names applied to their most typical colors. As pigments and dyes were found or manufactured, names were applied to their colors. Ochres, vermillion indigo, saffron, chalk and the Tyrian purple from cuttle-fish are types of pigments and dyes which were found early. Some peoples

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[21]Although this is the current form of the color theory, it is possible that gray is a separate, elementary sentiendum.

[22]The suggestion of "chlor" for this color was made by Dr. E. Q. Adams, of the Nela Research Laboratory; but not with regard to the adoption of this color as elementary.

applied the same name to quite different colors, because of their belonging to a common object. Thus, the Greeks of Homer's time had apparently but one word for green and blue, and that word was derived from one of their terms for the ocean. The Arabs also, according to Captain Burton,[23] apply certain names to more than one color, notwithstanding that they have, as a race, a keen color discrimination. We ourselves sometimes use the same words for discriminably different colors, although the range of inclusions under a single name is not so great as among more primitive peoples. Thus, we use "red" to indicate colors ranging from crimson to orange, and "blue" to indicate colors ranging between greenish blue and violet.

The total number of distinguishable colors is large: probably more than a hundred. The common list of seven "fundamental colors"—red, orange, yellow, green, blue, indigo and violet—is due to Newton's attempt to construct a color scale analogous to the seven-toned musical octave. If we include the various saturations of the colors, the number distinguishable is in the hundreds of thousands.

For convenience, we will refer to elementary red by the letter *R*, to elementary blue by *B*, and to the third (greenish-yellow) elementary color chlor, by *C*. *R* will then mean, not all of the colors commonly included under "red,"[24] but only the specific hue of red which is truly elementary; and *B* and *C* will be used in sim-

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[23]Burton, *Arabian Nights,* vol. VI., p. 111. "The names of colors are as loosely used by the Arabs as by the Classics of Europe; for instance, a light grey is called a 'blue or a green horse.' Much nonsense has been written upon the colors in Homer by men who imagine that the semi-civilized determine tints as we do. They see them, but they do not name them, having no occasion for the words. As I have noticed, however, the Arabs have a complete terminology for the varieties of horse-hues. In our day we have witnessed the birth of colors, named by the dozen, because required by women's dress."

The attempts made by Gladstone and others to show from the Greek color-names that the Greeks were defective in color vision have been clearly shown by Burton's work to be fallacious.

[24]We must constantly bear in mind that the application of color names varies widely even among people of "normal" color vision. Thus, what one person calls "blue", another will call "green blue", and what the second calls "blue", the first will call "violet", although both may actually see the same hues. Similarly, what one person calls "yellow" may be named "orange-yellow" by others. The sodium lines in the solar spectrum are described as "yellow" in some texts; as "orange" in others. In technical language, the name "purple" is applied to the whole range of fusions of red and blue, including crimson and violet. In popular usage, the term is usually restricted to the middle portion of this range.

ilarly specific meanings. To designate gray, we will use *N* (neutral); for black, *D* (dark), and for white, *W*.

The fusions of R with slight amounts of C produce the orange-reds and red-oranges. As the relative amount of C is increased, the fusions pass over to the true orange, and as the C component is still further increased, to the yellow-oranges and orange-yellows. When the C reaches a certain relative magnitude, the R being relatively small, we obtain yellow.

By fusions of C with a relatively small amount of B, we obtain the yellow-greens. As the relative amount of B is increased, we approach green, and by still further increases of B, the C becoming relatively small, we obtain the bluish greens and greenish blues.

From R and B the whole series of purples are fused, from "crimson," which is a slightly bluish red, to "violet," which is a slightly reddish blue. In the "magentas" we have a more nearly equal proportion of R and B.

The whole range of visible colors is represented in the planar scheme of Fig. 2, the three elementary colors being placed at the vertices of the triangle, and gray, (the balanced fusion of all three) at the center. Points along the line between R and C represent the fusions of these two sentienda only: points along the line from C to B and from B to R also representing binary fusions. Fusions of all three sentienda, in any proportions, including the balanced proportions required for N, can be represented by points within the triangle. Thus, the line from B to N represents fusions of B with schematically equal proportions of R and C, the proportion of B decreasing, and the proportion of R and C together increasing, as N is neared. In other words: the line represents the fusions in which the proportion of gray increases progressively and the proportion of B decreases, until finally pure gray is reached. The prolongation of the line to OY (yellow-orange) represents still further decrease in the proportion of B until it reaches zero, the proportion of R to C remaining the same throughout.

The predominance of any one simple color, or any fusion of two together, in a fusion of all three, is called *saturation*. The more nearly equal the proportions of the three—that is to say, the greater the amount of gray in the color—the less or lower is the saturation. Any line from N to the boundary of the triangle, there-

fore, represents a series of saturations of a certain color, the highest saturation of which is represented on the boundary line.

The proportions of elementary colors required to produce a certain fusion or hue are not fixed, but depend on the condition of the receptors. A mixture of stimuli which produces a certain green with one condition of the receptors, may be in other conditions yellowish or blue. A mixture which is N at one time may be reddish, or greenish, or bluish, or of some other hue, at another. Moreover, under the same working conditions, different eyes may

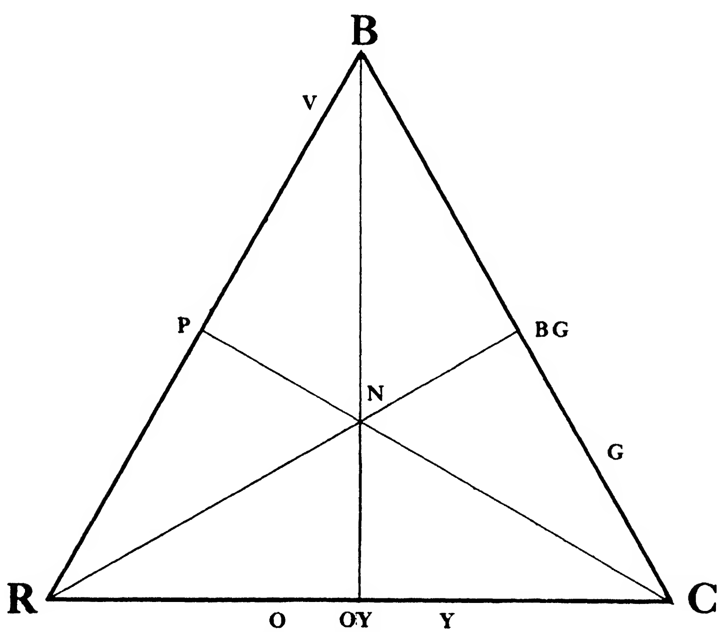

Fig. 2.—Color triangle. The three primary colors, Red, Blue, and Chlor, are represented at the vertices of the triangle. Other colors, being binary mixtures, are represented along the lines joining the vertices. Mixtures of all three colors, *i. e.*, colors of reduced saturation are represented within the triangle, with the "balanced" mixture, or gray, at N. Colors lying on opposite sides of N, on a straight line passing through N, are complementaries. Since all colors seen under normal conditions are of reduced saturation, *i. e.*, contain all three primaries, such colors lie within the triangle. All colors are here represented at the same brightness.

see differently. A reddish gray for one person may be a neutral gray for another, and that which is green for one person may be even yellow for another. The conditions of variation in fusions will be described in later sections.

It is seldom possible to obtain colors in full saturation, and actual colors must be assumed to be fusions of all three elements,

although one, or perhaps in some cases two, may be relatively insignificant.

From the consideration of the color triangle it is obvious that for each color, pure or mixed, there must be another color which, when mixed with the first in proper ratio of intensities, will produce gray. For, since gray is a certain balanced ratio of the three simple colors, any mixture of two simple colors may have the third color, or a mixture of the third and one of the first two, so added as to produce the balanced mixture of the three. For example: a balanced mixture of R and C merely needs to have added the proper proportion of B: a mixture of R and C in which C is in excess needs not only B, but additional R, in order to produce gray.

Two colors which will mix to form N are said to be *complementary*. The color triangle is assumed to be so drawn that a line drawn through N from the point representing any color will, when extended, touch the periphery of the triangle again at the point representing the color complimentary to the first. Characteristic complementary pairs, with the approximate wave-lengths of their stimuli in millionths of a millimeter ($\mu\mu$) are[25] as follows:

Red	656 $\mu\mu$	blue-green	492 $\mu\mu$
Orange	607	greenish-blue	489
Orange yellow	585	blue	485
Yellow	564	violet blue	462

The complementaries of the hues from OY to BG are not in the spectrum, but require mixtures of long and short waves for their stimuli.

If we considered now not only the quality, but also the intensity, of colors, we shall need a tri-dimensional scheme for their representation. Such a scheme is presented in Fig. 3. In this figure, the line W-D represents the whole series of grays from black to white. This series, since the qualitative fusions are the same, is a series of intensities or brightnesses. Cross sections of the solid at any point parallel to the plane of the triangle R-C-B represent the whole color scheme, as in Fig. 2, but at different determinate brightnesses. The approach of all lines to two common points at D and W represents well enough the fact that above and

[25]For explanation of the wave-length measurements, see pages 62 and 63.

below certain limits all colors tend to become less saturated, as they are increased or decreased in brightness, and finally become pure gray (white or black) in either case.

Remembering that the fusions of colors are different at different times, according to the condition of the receptors, we will readily understand that even if the proportions of the solid were carefully calculated, Fig. 3 would represent merely one condition: at best an *average* condition; and that the actual form of the solid

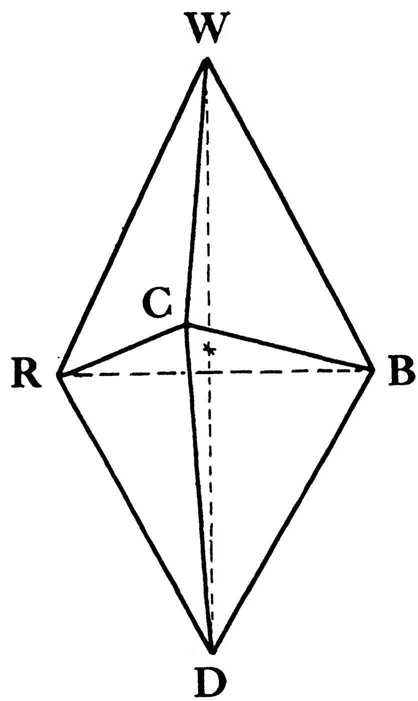

Fig. 3.—Color hexahedron. All possible colors, in all possible saturations and brightnesses, are represented in this figure, in which the line from W to D represents the whole series of grays from white to black.

scheme would vary greatly according to the receptor-conditions. The figure is to be understood as merely a scheme, not as representing exact metrical relations.

"White" and "black" are purely relative terms for varying high and low intensities of N respectively.[26] This can be strikingly

[26]Black and white are sometimes described as qualities, and gray as a mixture of the two. This usage has led to extreme confusion, and to still more bizzare hypotheses. If black and white are supposed to be qualities, it is necessary to assume

shown by selecting small pieces of "black" and "white" cardboard, and laying each on larger squares of properly chosen "black" and "white" cloth respectively. The cardboard will now no longer appear "black" and "white," but dark gray and light gray. These are not adaptation effects, such as are below described, but are instantaneous. If, now, a piece of the "black" cloth is placed on black velvet, and a piece of the white cloth is placed on white baryta paper, the cloths become gray. The blackest velvet, in turn, can be shown to be dark gray by comparing it with the greater blackness of an aperture in a box lined with black velvet. Adaptation effects may also change the degree of blackness or whiteness of any surface.

The receptors for vision are nerve cells in the *retina,* or inner lining of the eye. There are two kinds of these receptors, rod cells and cone cells, the former sensitive to gray alone, the latter to gray and colors. The stimulus is *ether vibration,* which is propagated from a source of light, or reflected from an object, into the eye, and there works upon the receptors. It is presumed that the student is familiar with the physical theory of light, and the following diagram and explanations are intended merely to refresh his memory.

The vibrations of the ether are mathematically represented as at right angles to the line of propagation; a scheme which may be illustrated nicely by waves propagated along a loosely stretched rope. At any given moment the displacement is in opposite directions at certain alternate points, and the wave length is the distance between points of equal and similar displacement, as between *e* and *e,* and between *d* and *d,* in Fig. 4. Since, however, ether oscillations of all wave lengths travel at the same speed in the same medium *(e. g.,* glass, or air); the frequency of the oscillation at any fixed point through which the waves are traveling will be inversely proportional to the wave length. It is possible, therefore,

either: (1) that there are different intensities of each, just as there are of the colors, or else, (2) that there is no intensity of color, and that the varying "brightnesses" of colors are merely different saturations. This last supposition has virtually been made by some authors. The first supposition is obviously incompatible with the main hypothesis, since a lowered intensity of black would be exactly what is obtained by mixing a little white with black. No hypothesis will square with the facts except the hypothesis that the difference between white and black is a difference in intensity.

to designate a system of waves either by its wave length or its frequency, but the *wave length* designation is usually adopted for light, and the lengths are measured in millionths of a millimeter, for which the symbol $\mu\mu$ is adopted.[27]

Ether vibrations of wave lengths between 760 $\mu\mu$ and 390 $\mu\mu$ approximately, will stimulate the receptors of the normal eye, under usual conditions. The intensity of the light (amplitude of the ether waves) is, however, a part of the determining condition and as the intensity is reduced, the range of stimulation becomes somewhat shortened. Even with optimal intensities the range is

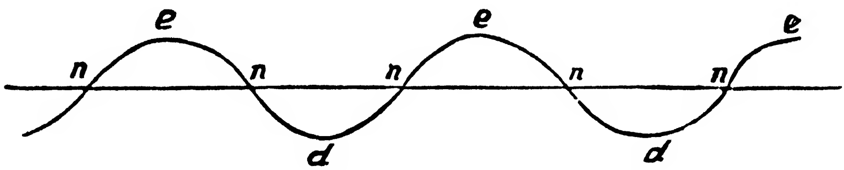

Fig. 4.—Wave motion in the ether. The loops e, e, e, d, d, d, represent the lateral displacements: The nodes n, n, n, n, n, are the points of no displacement.

shorter for certain "color blind" or "color weak" individuals who will be described later.

The Spectrum

Daylight, and the light of the most common artificial sources, such as the gas flame and Mazda lamp, considered as a physical stimulus, contains ether vibrations of all wave lengths included in the visible range, as well as a considerable range of "invisible" *(infra-red)* rays longer than the longest visible rays, and a further range of "invisible" (*ultra-violet*) rays shorter than the shortest visible ones.[28]

It is possible, however, to separate the total beam of mixed light into its component stimuli of different wave lengths by one

[27] Another unit of wave-length which is frequently employed is the "tenth-meter" *Angstrom Unit* (Abbreviated Å. U., or Å.) which is one ten-millionth of a millimeter. 1 $\mu\mu$. therefore, is equal to 10Å. Physicists incline to use the nomenclature (10^{-6}) millimeters; which may be read "ten to the minus six millimeters" or "millionths of a millimeter." The wave length of the D line in the solar spectrum, for example, may be read: (approximately) 589 $\mu\mu$., or 589 (10^{-6}) mm., or 5890Å.

[28] The expressions "visible rays" and "invisible rays" are convenient in speaking of visual stimuli, in spite of the fact that, strictly speaking, no ether-vibrations of whatever length are ever seen.

of several optical procedures. The most convenient of these procedures is by the use of a prism, used either with or without lenses.

In Fig. 5, I, is shown the simplest arrangement for producing a prismatic spectrum. Rays of light from a source, K, which should be as small as possible, approximating a point, are intercepted by the screen L, in which a slit, M, permits the passage of a narrow band of rays. These rays, approximately parallel, if K is some distance removed from L, are bent (refracted) out of their course by the glass prism, N, the red rays being least bent, the violet most bent. The fan-shaped beam is intercepted by the dif-

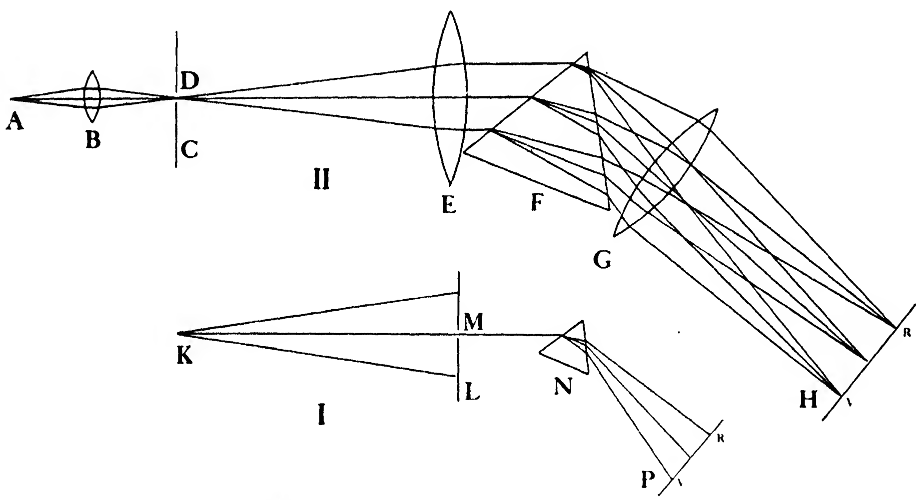

Fig. 5.—Scheme of Spectrum production.

I. Simple scheme. Light from the source K passes through the narrow slit M in the screen L, is dispersed by the glass prism N, and forms the spectrum V-R on the screen P.

II. Scheme actually used in spectral light apparatus. The lens B brings light from the source A to a focus in the slit D in the screen C. The beam of light, diverging from D, is rendered parallel by the lens E (collimator lens), dispersed by the prism F, and again focussed by the lens G as a series of images of the slit, forming the spectrum V-R on the screen H. By this method a spectrum of adequate brightness may be obtained.

fusing screen, P, on which therefore the spectrum, with the colors in order R, O, Y, C, G, B, V are seen.

A spectrum produced in this manner is very faint and not observable unless the eye is dark adapted. For practical purposes an arrangement such as that in Figure 5, II, is employed. An image of the source, A, is formed on the slit, D, of the screen C. The rays diverging from D are rendered parallel by the lens E (collimating lens), refracted by the prism, F, and brought to foci by the lens, G, on the screen H. A spectrum of high brightness

may thus be obtained. This arrangement of lenses and prism is employed in the common sorts of spectroscopes, spectrometers and spectrophotometers, with an additional lens in an eye-piece (not shown in the cut) through which the spectrum at H is viewed.[29]

The light rays physically analyzed as described above, and falling upon a "white" or gray surface, constitute the *spectrum.* The exact nature of the spectrum will depend upon the nature of the light-source used: for convenience, the spectrum obtained from sunlight—the *solar spectrum*—may be considered.

In Fig. 6 is shown schematically the visible part of the prismatic solar spectrum, with the approximate position of the Fraunhöfer Lines. These lines, which are due to light absorption in the earth's atmosphere and in the gaseous envelope of the sun, are convenient points of reference, since they correspond to definite bright lines in the spectra of various chemical elements, and have

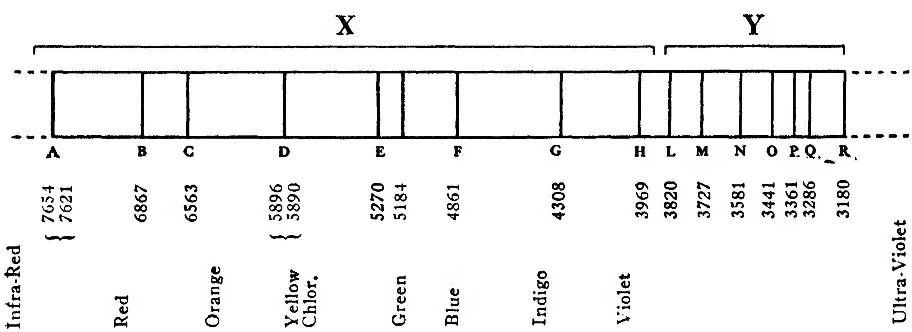

Fig. 6.—Diagram of a typical prismatic spectrum of sunlight. The part of the spectrum visible at moderate intensities is included under X: the part visible at higher intensities under Y. The chief Fraunhofer lines are represented with the letters by which they are conventionally designated. The wave lengths of these lines are given in *Angstrom units.*

definite wave lengths. The exact relative positions of these lines depend upon the material and angle of the prism.

In the "visible" part of the solar spectrum, the wave lengths for the normal eye under normal conditions range from approximately 760 $\mu\mu$ in the extreme red to 390 $\mu\mu$ in the violet: the part included under X in Fig. 6. The range for any normal individual may be slightly greater or less than this. In this part of the spec-

[29]As a matter of fact, a certain amount of white light is mingled with the spectral colors, on account of reflection internal to the prism, and further refraction is necessary to obtain a "pure" spectrum. But for many practical purposes, a spectrum obtained in the way described is satisfactory.

trum, the colors seen are ranged in the order from red (760 to 690 $\mu\mu$) through orange (660 to 590 $\mu\mu$), yellow (585 to 580 $\mu\mu$), green (525 to 500 $\mu\mu$), and blue (460 to 435 $\mu\mu$) to violet (420 to 390 $\mu\mu$). Under very favorable conditions of brightness and purity of the spectrum, and adaptation of the eye, the visible part of the spectrum may include also the part under Y in Figure 6, extending as far as the R line, whose wave length is 318 $\mu\mu$ (3180Å). Beyond this visible violet is the "ultra-violet" invisible part of spectrum: and beyond the red, at the other end, is the "infra-red" invisible part. We shall consider only the visible part of the spectrum from this point on.

It is noticeable that the spectrum contains no purples,[30] except for the slightly reddish-blue which we call violet, but that aside from the purples it contains all known hues. From studies, into the details of which it is not necessary to go here, it is concluded that practically any wave length of the spectrum, from 760 $\mu\mu$ to 390 $\mu\mu$, corresponds to all three of the elementary colors, but to these colors fused in proportions varying widely, and in accordance with variations in wave length of the stimulus. In other words: in the colors *seen* at different parts of the spectrum, by the normal eye under the average conditions, all three elementary colors are present. Even in the "purest" red of the spectrum, as seen under ordinary conditions, there is a little B and a little C, combining with a balancing amount of the R to give, in effect, a slight amount of N which reduces the saturation of the red as seen.

The proportions of R, C and B in the different colors of the solar spectrum as seen by the normal eye, may be roughly represented by such a scheme as that given in Fig. 7.[31] The base line (ab-

[30]Perhaps a very slight violet or crimson-red at the end of the spectrum.

[31]The curves for the three fundamental colors presented in Figs. 7 and 8 are not intended to represent definite metrical relations between the intensities of the three processes. Such relations would, of course, vary with the exact spectrum employed, depending upon the source and upon the prism (or diffraction grating) employed. Moreover, the relation between intensities of the elementary colors, as directly compared and the "mixing values" of these colors, is a complicated and uncertain one. The proportions of the three which "balance", or produce white, for example, are not proportions which when compared photometrically, seem equally bright. The "balanced" ratio we have described as *schematically* equal values. Again, the schematically equal values of R and C, which give in the mixture of the two a balance, or a predominance of neither, are not equal in brightness. Attempts have been made by König, Abney and others to work out metrical relations between the three colors, but it is doubtful whether measurements made by their methods have any significance aside

cissa) represents the spectrum extending from extreme red to exreme violet, and the ordinates of the three curves represent the ·elative proportions of each of the three elementary colors pres·nt at each point in the spectrum. At G, for example, C and B ıre present in schematically equal proportions, with a small ımount of R. Looking at the scheme from the point of view of a ;ingle elementary color, as for example, C, we see that it is pres·nt in highest degree near the middle of the spectrum, being pro-;ressively less represented towards both ends. In this diagram,

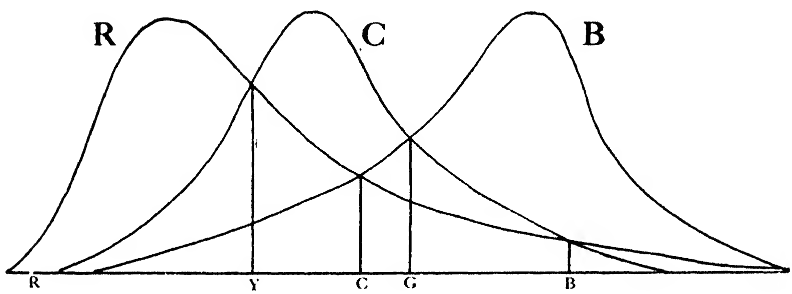

Fig. 7.—Color sensitivity of the normal eye. The excitability of each of the three color-rocesses for wave lengths from the extreme red to the extreme violet is represented by the rdinates of the corresponding curve, points on the base line representing the various wave-engths. R, Y, C, G, and B represent the points at which the purest red, yellow, chlor, green nd blue occur.

·epresentation of exact metrical relation is not attempted, and in liverse conditions of the visual sense organs, the distributions are naterially altered.

The Physiological Hypothesis of Color Vision

For further explanation of the phenomena of color vision it s convenient to depart from the discussion of the actual data of ·xperience, and speak in terms of a physiological hypothesis, renembering that this is merely a hypothesis, and hence nothing nore than a linguistic device for grouping and studying the facts. Concerning the actual physiology of vision, very little is known.[32]

The perception of colors, according to a widely accepted theory,

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rom the assumptions made by the investigators. In the curves of Figs. 7 and 8, the naximal excitations of the three processes in a given spectrum are arbitrarily repesented by equal ordinates.

[32]The so-called physiology of vision, as commonly presented is mostly psychology. 'he histology of the retina is well known, and so also is something of its chemistry. ;ventually, perhaps, the real visual physiology will be worked out.

is supposed to depend upon three sorts of activity[33] in the retinal receptors. One of these sorts of activity is assumed to be capable of initiating the reaction process through which R is perceived, and may here be called the r-process. The other two processes are capable of initiating the reactions through which C and B are respectively perceived, and hence may be called the c-process and the b-process respectively. When all three activities occur in "balanced" proportions, the reaction through which N is perceived may be initiated, and by other combinations of r, c and b are initiated reactions through which the various fused colors are perceived.

Returning now to the spectrum, we find that the scheme of Figure 7 represents also the relations of stimuli and receptor-activities in accordance with our hypothesis. The abscissae represent the wave lengths in the spectrum from 390 $\mu\mu$ to 760 $\mu\mu$ and the ordinates of each curve represent the relative degree to which ether vibrations of each wave-length excite the r-, c- and b- processes respectively.

The Lag or Latency of the Visual Stimuli

We can measure the time relation of visual stimuli and perceptions with some accuracy—which is not possible for taste and smell—and we find that there is a decided lag or latent period between the beginning of visual stimulation and the beginning of the perception; and another definite period in most cases between the termination of stimulation and the termination of perception. The first period is the *initial lag;* the second is the *terminal lag* of vision. The initial lag is usually a matter of a few *sigma,* (σ: *sigma* is the symbol for .001 second),[34] but the terminal lag may be a matter of seconds, or even minutes. The light or color, in other words, is not perceived until a few sigma after the eye has been exposed to it, and it may be perceived long after exposure has ceased.

That the terminal lag of vision is greater than the initial lag

[33] As to the exact nature of these hypothetical activities, no suppositions need be made. The supposition that there are three kinds of receptors is usually excluded, but the grounds for such exclusion are by no means final. We have employed the capital letters R, C, and B to designate the primary colors as seen, and the lower-case letters r, c, and b to designate the hypothetical physiological process.

[34] Although the symbol σ (sigma) is commonly used to indicate the thousandth part of a second, physicists are inclined to use the symbol (10^{-3}) sec.

is most strikingly demonstrated by the phenomenon of fusion of intermittent flashes of light. If a beam of light is interrupted by a sectored disc, rotating at increasing speed, the flashes of light resulting, soon merge into a *flicker,* and then, when a certain rate of intermittence (the rate of which is called the *critical frequency for light)* is reached, the light appears perfectly continuous, and no further increases in rate of intermittence produce any effect.[35] The critical frequency depends upon the intensity of the light, and on the condition of the eye: for bright light it may be as high as 50 flashes per second.

The terminal lag of vision is greatest for a bright light, to which the eye is exposed briefly. It may be demonstrated by means of a projection lamp and a screen of white cardboard, or white glass a few inches square. When the white screen is held a few inches from the objective lens of the projection lamp, a bright spot is formed by the concentrated rays: but if the card is moved rapidly (edgewise) through this point, the bright spot which flashes out momentarily on the card is seen "hanging in the air" after the card has passed through the beam.

The after-effect of light of sufficient intensity and brevity may be prolonged beyond the period of terminal lag into the so-called *positive after-image.* This is best seen in a dark room after exposing the eyes to a bright light for one or two seconds. Then, if the eyes are kept open, and *at rest,* the light, with the same space-form it had during exposure, will reappear and persist for some time.[36] Eye movement causes the after-image to disappear, but

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[35]The phenomena of flicker and critical frequency may be most conveniently illustrated by means of a solid disc with alternate black and white sections, illuminated from a steady source.

[36]This after-image should properly be called the *continuation image.* It may be obtained from the filament of an incandescent light turned quickly on and off in a dark room, or from a window in an illuminated box covered with suitable white or colored glass with a diaphragm of such shape as to outline a figure. With longer original exposures, adaptation modifies or destroys the effect; adaptation and further stimulation may turn the positive image into a negative one. It is remarkable that the positive after-images, although more difficult to obtain than the negative ones, were described by Aristotle, while the negative ones were not mentioned.

Intermediate between the primary light (as extended by the terminal lag) and the continuation image, there may be two or three brief positive after-images, separated by dark intervals. The first of these, following the primary light by approximately 50 σ, has recently been called Henry's after-image, and the second, following a somewhat longer dark interval, Purkinje's after-image. These are brief, and brighter than the continuation image above described, although dimmer than the primary light during its period of terminal lag.

it may reappear if the eyes are held again at rest. This after-image may appear in the original color, or in one or a succession of the component colors of the original.

Visual Adaptation

Adaptation is of especial importance in vision, and here it can be shown very definitely that there is adaptation which is not fatigue.

The general law of visual adaptation is that when the eye is subjected to feeble stimulation, its receptors tend to increase in sensitivity to that stimulus; and when subjected to intense stimulation, tend to become less sensitive to that stimulus.

Adaptation to white or nearly white light is easily noticeable. On going from daylight into a dimly lighted room, the perceived light is dim at first, and in the course of some minutes, becomes brighter, and vision becomes clearer. Fifteen or twenty minutes are required for practical adaptation to a dim light, but the adaptation actually improves for several hours. Conversely, on passing from a dim to a bright light, the eye becomes adapted to the intense illumination, and the brightness of the perceived light is soon reduced, the adaptation in this case being much more rapid than in passing from a bright to a dim light. This adaptation phenomenon, in which there is no appreciable change of color, is called *brightness adaptation.*

If the stimulation is not "balanced," that is, if the light is not "gray," the phenomenon takes still another form, described as *color adaptation.* Any color, pure or fused, tends to become less saturated, if it is steadily seen. Expressed in terms of our physiological hypothesis: if the receptors are stimulated in such a way that the three processes are unbalanced, and one or two predominate, continuation of the stimulus tends to bring the processes towards balance, the more highly excited process or processes becoming progressively less sensitive, and the more feebly excited processes or process becoming progressively more sensitive.[37] For example: if one stays in a room illuminated by light which at first; as one comes in from daylight illumination, is green-

[37]The phenomenon may be observed by wearing colored goggles which fit the face so closely that all light, except that coming through the lenses, is excluded.

ish, the light becomes progressively less saturated, and eventually, after an hour, more or less, according to conditions, becomes practically gray. Obviously, in this case, the C and B processes have decreased in sensitivity, and the R process increased, until all three are finally excited in the normal "balanced" ratio. Color adaptation will occur whatever the absolute intensity of the light, but the total brightness may increase or decrease in accordance with the absolute intensity of the stimulus. That is to say: as the three processes approach the same level of excitability for the stimulus applied, the average level of excitability for all three may be raised or lowered.[38]

So far, we have considered adaptation only as affecting the whole retina. But the same phenomenon may be demonstrated where only small parts of the retina are involved, and the demonstrations are still more striking.

If a small square of black paper is put on a large white or gray card, and one then gazes for some seconds fixedly at the center of the square, and then removes the black square without changing the gaze, or better, fixes the gaze on a definite part of another white or gray surface, then a white spot, *i. e.,* a spot of brighter gray, will appear where the black was. This is the so-called *negative after image,* and is a pure adaptation phenomenon. The portion of the retina on which the image of the black square fell has increased in sensitivity as compared with the surrounding area; and now when the whole area is subjected to equal stimulation, there is greater response in the darker adaptated area.

The reverse effect—due to the same adaptation process—may be obtained by using a white square on a black background, and transferring the gaze to a light gray surface as before. If, instead

[38]Brightness adaptation is, therefore, in part, due to the same causes as color adaptation. So far as the fovea, in which there are only cone-receptors, is concerned, brightness adaptation and color adaptation are probably the same essential phenomenon. But outside of the fovea, adaptation in the rod-receptors has apparently nothing to do with color adaptation. The rod adaptation is in large part due to increase or decrease in a chemical known as *visual purple,* and brightness adaptation of both cones and rods is in part due to protective action of retinal pigment cells, which under strong illumination shield the receptors from the light. Such protective action of the pigment occurs at least in the eyes of some lower animals, although its occurrence in the human eye has been doubted.

of a black or white spot, a colored test object is used, a negative after-image of complementary color is obtained.[39] This is an adaptation phenomenon precisely like that previously described, as affecting the total visual field.

Simultaneous Contrast

The adaptation of one area of the retina by stimuli applied to that area also produces similar adaptation changes in adjacent retinal areas. This phenomenon is readily demonstrable if a large area is adapted to color, while a smaller area completely enclosed within the first is stimulated by white light. If a small piece of gray paper, or still better, a narrow ring of gray, is placed on a background-sheet of colored paper, (red, for example), and a point in the gray paper (or a point in the center of the ring) is steadily fixated, the gray will soon take on a hue complementary to the color of the background. If, for example, the background is red, the gray will become tinged with bluish green. Obviously, the reduction in sensitivity to R and increased sensitivity to C and B has occurred on the gray-stimulated as well as on the red-stimulated area. This phenomenon is conventionally called *simultaneous contrast* or *negative color-induction.*

Color contrast is at its highest when the background color and the gray are of approximately equal intensities. It may be still further heightened by one of several procedures: (1) by "squinting" with the eyes closed as closely as will permit vision; (2) by reducing the illumination falling upon the paper, as by lowering the window shades, or placing the test object in a shadow; (3) by placing a sheet of ground glass, or a sheet of tissue paper covered by clear glass, over the test object; (4) by using for a test object a set of rotating discs; *e. g.*, a large colored disc with a smaller pair of black and white Maxwell's discs (see below) over that, and over the Maxwell's discs a still smaller disc of the same color as the largest disc; and rotating the whole combination at a rate greater

[39] Often when looking at a spot of color on a gray background one sees the spot edged with the complementary color. This is the so-called *edge-contrast*. It will not occur unless the gaze is unsteady, *i. e.*, the eye wanders slightly. The student should be able to explain this as an adaptation phenomenon.

that the critical frequency. The reasons for the intensification produced by these devices is at present entirely unknown.[40]

If a piece of paper of some color other than that of the background is used instead of the gray, the contrast effect is still produced, the effect being that of adding the contrast color to the color of the small area. Thus, if blue is laid on red, the blue becomes greenish (B + C): if a complementary color is used, the color is intensified. Other mixed effects may be produced by placing a small strip of gray (or color) between the wide surfaces of two different colors.

The importance of contrast effects in contiguous color combinations occurring in nature or in art can easily be comprehended. The more nearly complementary are two colors in a costume, for example, the more striking is the difference, and hence the more striking the effect. The nearer alike are two colors, the greater is the "softening" effect upon each other.

Color Mixing

Various methods of mixing colors experimentally may be used, but one of the most convenient is by use of *Maxwell's discs,* customarily referred to as "maxwells." These are discs of colored paper or cardboard with holes punched in the center to fit an arbor on an electric motor shaft, and split radially from hole to periphery, so that two or more discs can be straddled together. These can then be placed so that any desired angular proportions of the several colors used may be exposed, and when the combination is rotated at a rate higher than the critical frequency, a smooth fusion is obtained. The retinal image of the disc-combination rotates at the same angular speed as that of the discs, and the receptors are therefore stimulated by the colors alternately. The effect produced is equivalent to a mixture of the light reflected from the two colored surfaces, not that of mixing the two pigments with which the surfaces are colored.

By the use of five maxwells of the same diameter: Red, Green-

[40]It has been said that the effect of the ground-glass or tissue paper is produced through the elimination or blurring of the contour lines between the gray and the color. This is disproved by the fact that accentuation of the contours by the drawing of fine black lines on the edges of the gray does not decrease the contrast effect.

ish Yellow, Blue, Black and White, in various combinations, all colors, in all saturations up to the saturations of the discs employed, together with the whole series of grays from black to white, can be obtained. From R and C, the series of colors from red through orange and yellow can be obtained by employing the various angular proportions of R and C. From C and B, the yellow-greens, greens and blue-greens can be obtained; and from B and R, the purples, from violet through magenta to crimson. By combining the black and white discs with one or two of the colors, the colors may be reduced in saturation and in brightness, or may be reduced in saturation and increased in brightness. Many of the color relationships described in the preceding pages may be illustrated by means of these discs.

Mixing of pigments does not produce the effects of mixing colored light. Thus: a mixture of complementary yellow and violet-blue paints produces, not gray, but green: this effect is similar to that produced by passing white light through a yellow and a violet-blue glass in succession, and is a composite subtraction effect. It is important to remember that pigments produce their effects by absorbing or subtracting certain colors from the light falling upon them, and reflecting the remainder.

Central and Peripheral Vision

We have spoken so far of the adaptation effects which produce manifold changes in the colors of objects seen, with the tacit assumption that the colors are presented to the *fovea*, or central area of the retina (the area of clearest vision). In the usual states of adaptation, however, colors are seen differently by the fovea, the paracentral area (area surrounding the fovea) and the peripheral parts of the retina.

The effect of moving a colored stimulus from the center to the periphery of the retina is strikingly like the effect of color-adaptation. The color, after passing out of a small central area, begins to show decreased saturation, and may become pure gray as it nears the extreme periphery. As saturation decreases, on account of displacement toward the periphery of the retina, the color may change: the hues from purplish red to green become yellow, and the hues from greenish blue to reddish purple become

bluer. Yellow, blue, a certain green, and a certain purple show no change except reduction of saturation. The degree of saturation-reduction is dependent upon both the intensity and the duration of the stimulus; high intensity and brief duration being productive of relatively higher saturation in the peripheral retina. The phenomenon may be described as due to a permanent partial color adaptation of the peripheral retinal receptors; or perhaps to a greater rapidity of adaptation changes in the periphery as compared with the center.

The differences between central, para-central and peripheral vision are supposed to be due chiefly to the difference in sensitivity between the rod cells and the cone cells. In the fovea, there are cone cells only. In the para-central region, rod cells are found also, and the rod cells increase in relative numbers with the distance from the fovea, the extreme peripheral portion of the retina containing rod cells but no cone cells.

Defects of Color Vision

Certain individuals have characteristic permanent defects of central retinal vision which suggest both adaptation phenomena and the peculiarities of normal peripheral vision. These defects are included under the terms *color blindness* and *color weakness.*

Some individuals, who are *totally color blind,* or *achromopsic,* see only gray. The solar spectrum and all other colored objects are for these persons merely different shades or intensities of gray. The difference between the visual world of these individuals and the world of persons with normal vision is comparable to the difference between a black and white sketch and a color print. In the visual receptors of these persons, light of any wave length excites all three color processes in the balanced ratio. (Fig. 7.) In some cases, it is believed that cone cells are absent, only rod cells remaining. In other cases, the cone cells are apparently in a permanent state of equal sensitivity to all stimulation, as are the normal rod cells.

Other individuals are *parachromopsic,* or *partially color blind.* The two most frequent classes of the partially color blind are *protanopes* and *deuteranopes,* who together are classed as *red-green blind.* The characteristic symptoms of these defects are: (1) per-

ception of low saturations of red and green as gray, and (2) confusion of certain dull reds and greens with browns.[41]

By careful work with the spectroscope it is found that both protanopes and deuteranopes are *dichromats;* that is, they see in the solar spectrum only two colors, lying on each side of a *neutral zone* which occurs in the part of the spectrum which is bluish-green for the normal eye. The dichromat cannot distinguish the neutral band from normal daylight, if the intensities of each are made equal; and he cannot on the same side of the neutral zone distinguish any one part of the spectrum from any other part, if the intensities and saturations are equalized. It is believed that the two colors seen by dichromats are blue and yellow: that is, B and a fusion of R and C. In other words: any wave-length of light which excites the R-process, also excites the C-process in equal proportions, and vice-versa.

The chief difference between the protanope and the deuteranope is that the spectrum is slightly shortened at the red end for the former: that is, the extreme visible red for the normal person is not visible at all, even as yellow, for the protanope. The deuteranope, on the other hand, sees the spectrum as fully extended at the "red" end as does the normal person (but of course sees it as yellow at that end). Certain slight differences in confusion of colors, as in sorting colored worsteds, are symptoms of the two cases. Protanopic color vision is represented by the curves in Fig. 8, which is to be compared with the curves for normal vision in Figure 7. The R and C curves, for the protanope, are superimposed, since any stimulus which excites one process excites the other also to a schematically equal degree. The general positions of the curve are as if the R curve were moved to the right, nearly to the position occupied by the C curve in the diagram for normal vision. The shortening of the spectrum at the red end is thereby represented.

The diagram for the deuteranope would be drawn in much the same way, except that the position of the combined R and C curves would be farther to the left, almost in the position of the R curve in the diagram for normal vision. This would represent, there-

41 "Browns" are yellows and orange yellows of moderate saturation and low intensity. Orange of low intensity and moderately low saturation gives *russet.*

fore, the unshortened spectrum, with neutral band slightly to the left of the neutral band for the protanope.

It is to be noted that these curves represent in a general way the actual conditions occurring in red-green color blindness, merely stated, for convenience, in terms of the three color hypothesis. In other words, the actual differences between the color vision of the normal eye and the color vision of the protanopic eye are represented by the difference between Figs. 7 and 8.

It has been believed that red-green blindness may be produced by systemic poisons, such as tobacco and wood alcohol. This theory at present does not seem established. In many cases there is no known cause, but the condition is inherited, apparently following the Mendelian laws. Inherited cases are sometimes de-

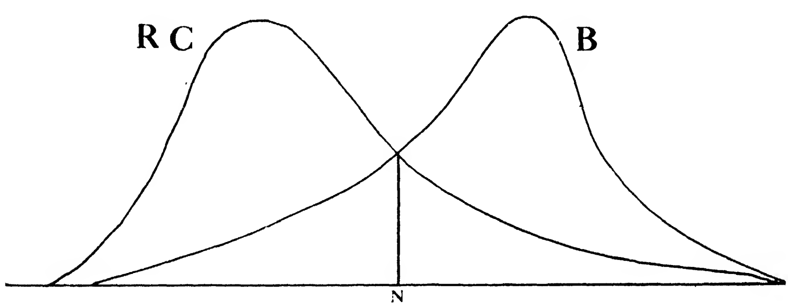

Fig. 8.—Color sensitivity of the dichromatic eye. The coincidence of the R and C curves represents the actual condition of sensitivity in both the protanopic and the deuteranopic eye. N represents the neutral band.

scribed as "congenital," although it is not known whether they are actually congenital, or developed in the period of puberty, or just preceding that period. It is possible that many cases of so-called tobacco color blindness are not due to the use of tobacco, but are merely hereditary parachromopsia developing at a somewhat late age. The occurrence of precisely similar cases in men and women who have never smoked is certainly significant. In these cases, the parachromopsia begins near the center of the fovea, and slowly spreads towards the peripheral retina. There is increasing evidence that all color blindness of the common red-green type begins in this way. So far as is known, nothing can be done to improve the vision of the color blind person.

The practical importance of color blindness may be grasped

by considering the great dependence placed upon color discrimination by mineralogists, chemists and men engaged in transportation by rail and water. It is singular that the colors most used as signals for danger and safety on land and sea (red and bluish green) are just the colors which offer the greatest difficulty in discrimination by the red-green blind. Many serious accidents on railroads have been due to color blindness of engineers, and although all train men now have their color vision tested, detection of color blindness is not easy, since many of the tests used are inadequate. If orange and blue signal lights were used, the danger would be very much decreased.

There are unquestionably types of partial color blindness other than protanopsia and deuteranopsia. In addition, there are mild degrees of the defect, known as *color weakness*. Some persons can distinguish the reds, greens, and spectrally intermediate colors at moderately high saturation and intensities, but not when the intensities and saturation are low. These individuals are unsafe as engineers and pilots, because smoke and fog often produce serious reduction in intensity and saturation of signal lights.

Another form of color weakness which is much more prevalent than was formerly supposed is reduced sensitivity to blue. Many persons are unable to distinguish between a blue of low saturation and intensity, and a gray of equivalent brightness. These persons have escaped detection frequently because no color tests were adequate to detect them.

It is sometimes said that there are relatively more men than women who are partially red-green blind. This may be true, but is doubtful. As tests of color vision are improved, more and more protanopic and deuteranopic women are discovered. Tests ordinarily given are passed frequently by red-green blind women and men, who have had experience in the handling of colors. Certainly, as regards reduced sensitivity to blue, there are as many defective women as men. In fact, there is ground for suspecting that there are more blue-weak women than men, rather than the reverse.

As regards the average percentage of red-green blind to the total population, we may reasonably conjecture that there are about two per cent of such defectives. But the percentage varies

so much in different stocks—being apparently less than one per cent among college men in some Western universities, and as much as four per cent in other groups—that no reliable statement can be made until more comprehensive and more adequate tests have been made. The principal basis for statistical statements at the present time is in the results of testing railroad men. Tests have not been made on a comparable group of women.

Data in color defects obtained from officers and men of the United States Army in the recent war are unfortunately of no value for statistical purposes, as the tests used were inadequate and in many cases were not given expertly.[42]

It must not be assumed that absence of physical light-stimulus means absence of visible light. In complete darkness, some physiological stimulation of the visual receptors goes on and gives rise to what is known as *idio-retinal light*. This light is usually faint, and varies in different parts of the visual field. In some cases, it is quite bright in the dark adapted eye, and various colors may appear as the r-, c-, or b- processes predominate or are minimized. The idio-retinal light is practically absent for a few moments after physical stimulation has ceased, and is inhibited in unstimulated areas surrounded by areas of considerable intensity of stimulation. In these cases the extreme degrees of "black" are perceptible.

There are many interesting phenomena of vision into which the limitations of an elementary text forbid us to go. Some of these phenomena have been analyzed experimentally in great detail, and furnish an interesting field of work for the advanced student of sensory psychology.

Note

Theories of Color Vision. The form of presentation we have followed above is known as the "three color" or "Young-Helmholz" theory. The original theory suggested by Thomas Young and developed by von Helmholtz differs in certain essentials from the modern theory. The modern three-color theory is the simplest yet constructed, and has the virtue of fitting all the facts. Many more complicated theories have been evolved, among them the theory of Hering, which has been much favored by physiologists. This theory assumes six fundamental colors—purple-red, golden-yellow, bluish-green, violet-blue, black and white; and assumes further that these are tied up in pairs with three reversible processes in the receptors: "red" and "green" with

[42] A number of typically red-green blind men passed the tests successfully and received commissions in the Air Service.

one, yellow and blue with a second, and white and black with the third. The "red" process is based on the breaking down of a certain hypothetical chemical, and the "green" process on the building up of the same substance. Similarly, vision of yellow and white are assumed to depend on the breaking down of a second and third substance respectively, and vision of blue and of black on the restoration of these substances. In the condition of equilibrium of all three substances, no color is seen, but "gray" appears. The working out of the application to various color phenomena makes the theory very complex, and since it fails to fit all the facts of color-blindness, it need no longer be considered seriously.

An interesting attempt to give the modern three-color theory a genetic basis has been made by Christine Ladd Franklin. She assumes that the totally color-blind eye is the most primitive type of eye: that the next stage of development produced the dichromopsic eye (with yellow and blue vision only), through the separation of the primitive "color substance" which is assumed to sensitize the receptors to light, into two substances, one sensitive principally to the long, the other to the short, waves of the spectrum. In the final stage of development, the "yellow substance" has separated into two: the "red-substance" and the "green-substance," thus producing the "normal" color vision of the human animal. These two stages of evolution have occurred only in the cone-cells, however, the "color-substance" in the rod cells remaining in its primitive, undifferentiated condition, and hence color can not be perceived through rod-cell functioning.

If the three-color theory needs essential modification, the assumption that white is the summation of R, C and B is to be called in question. The assumption of white as a fourth process may be necessary.

§4. Audition.

Auditory data are sounds, which include *tones* and *noises.* Under tones are included all sounds which have a distinct pitch: such sounds as the notes of a flute, organ, steam whistle, and human voice. *Noises* are sounds which have less definite pitch. There is, however, no dividing line between the two groups: there is a continuous gradation between the clear or "musical" tones, through noisy and noisier tones, over to noises which have little or no musical quality.

Tones and noises alike are analyzable into *simple tones.* Almost all musical tones contain a number of such simple tones, and the number of simple tones in a noise is very large.

Simple tones differ from each other in pitch, in intensity or loudness, and in duration. Whether they differ in quality and in extensity remains to be examined. It is sometimes said that pitch differences are qualitative differences, that is: that pitch is the quality of auditory sentienda. But actually the pitch relationships of tones, which are as definitely known as are the qualitative relationships of tastes and of colors, are not comparable to those qualitative relationships. The series of pitches is continuous from the "lowest" to the "highest" and is adequately repre-

sented by a straight line. But this line does not represent an order of fusions of qualities represented by the ends of the line, as in the case with the line between sweet and sour, and the line between the colors R and C. There are no fixed points on the line at all: the musical scale may start with any pitch whatever in the total series and be equally accurate. The series of pitches, in short, is not a qualitative series at all, but is a quantitative series like a series of extensities, intensities, or durations.

Since both the intensity and the duration of tones vary independently of pitch, we are forced to adopt the hypothesis that pitch is the extensity character of tones; and this theory fits the facts of tones and tone perception so far as we know them.

The stimulus for audition is vibration transmitted through the

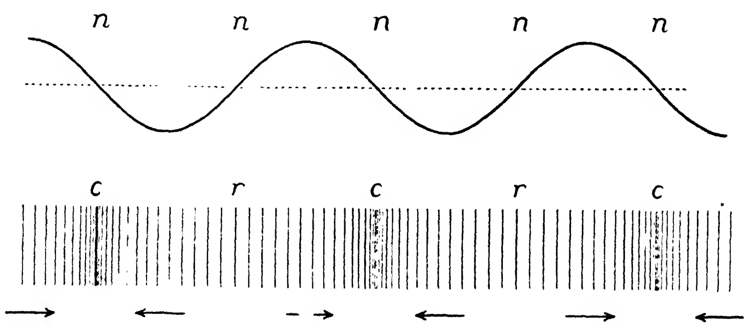

Fig. 9.—Wave form of pure tone. Drawn after Dayton C. Miller, *The Science of Musical Sounds*. The lower part of the figure represents the phases of compression (c) and of rarefaction (r) in the air, the arrows indicating the directions of movements of air-particles which have produced these phases. The upper part of the figure shows the way in which the sine curve represents these phases. The nodes (n) represent the points of maximal compression and rarefaction, and the ordinates of the curve represent the relative amplitude and direction of movement of the air particles.

air, or other substances, and ultimately affecting receptors located in the cochlea of the inner ear. Sound-vibration differs from light-vibration essentially in that the particles of air or other substance oscillate in the line of transmission of the sound, and not transversely, as is the case with ether vibrations. Nevertheless, these vibrations may be represented by a periodic curve, just as light-waves are represented.

The lower part of Fig. 9 represents directly the conditions occurring in a sound wave of a simple tone during one phase of the vibration. Air particles lying between *n* and *n* move towards *c*, causing compressions at *c* and rarefactions at *r*. In the next

phase, not represented, the direction of movement is reversed, so that there will be rarefaction at each of the points marked *c*, and compression at each of the points marked *r*. For convenience, short lines are used to represent air particles.

The sinusoidal curve in Fig. 9 represents the movements of the air particles, the elevations, and depressions of the curve representing movements towards the right and left respectively. At the nodal points there is no movement.

Pure, or simple tones have stimuli in which the oscillations of particles of the transmitting medium are pendular, and are represented by simple sinusoidal curves. The period of the curve, that is, the distance from one phase to the next exactly similar phase, is the wave length; and the extreme distance by which the curve deviates from the axis is the amplitude. In any given medium, the amplitude corresponds to the intensity or loudness of the tone, and the wave length to the pitch.

The stimulus for a complex tone is not simple pendular oscillations of the air, but a complex form of movement, which is the synthesis of all the simple wave forms of the stimuli of the simple tones which make up the complex tone. In Fig. 10 the curve at the top represents the actual wave form of the note of a certain organ pipe, and the curve numbered from 1 to 12 represents the wave form of the partials from the first to the twelfth, which make up that note. The algebraic addition of the ordinates of these twelve curves gives the upper curve almost exactly, the partials above the twelfth being negligible. Each of the simple wave forms into which a complex wave form is analyzable corresponds to a real partial in its complex note: but there are in many cases additional component tones (difference tones: see below) which have no corresponding simple components in the stimulus.

The vibrations of the sound stimulus travel through any uniform medium *(e. g.,* air or copper) at a uniform rate, regardless of the wave length, although the rates of travel in different media may be quite different. Ether vibrations also, of all wave lengths, have a constant speed of travel through a uniform medium. In any medium, therefore, the frequency of either stimulus is related in a simple numerical way to the wave length. The sound stimulus of 256 vibrations per second has, in any medium, a wave length

of exactly twice that of the sound of 512 vibrations, in the same medium; and the frequency of ether vibrations of 300 $\mu\mu$ is twice that of vibrations of 600 $\mu\mu$ in any given medium. In either case, therefore, the standardized measurements of the stimuli might be made in terms of either wave length (in a specified medium) or of frequency. On account of various practical considerations of measurement, sound stimuli are customarily measured in fre-

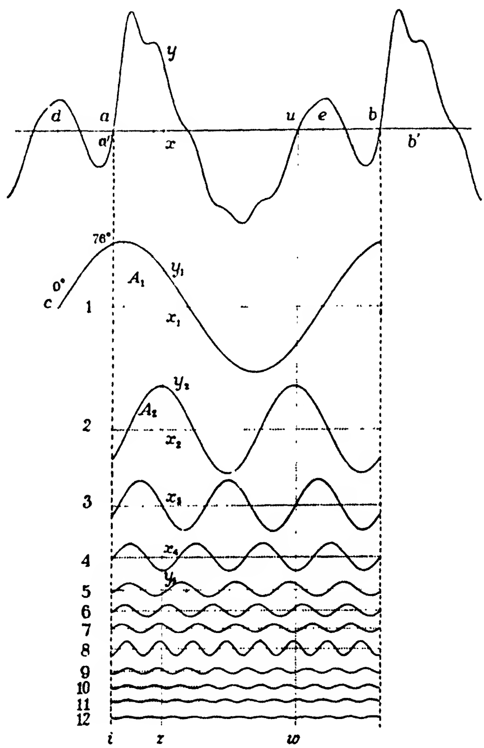

Fig. 10.—The wave form of an organ-pipe tone (reedless oboe, middle C, 260 v.s.), with its harmonic partials. By permission, from Dayton C. Miller, *The Science of Musical Sounds*. The upper curve represents the actual wave form, with a complete wave from a to b, as photographed with Miller's phonodeik. The true axis is the dotted line a'b'. For any abscissa, as x, the algebraic sum of the ordinates, x_1, x_2, x_3, etc., of the partials, measured from the true axis, a'b', is equal to the ordinate, y, of the actual wave. It will be noticed that the maxima, A_1, A_2, etc., of the partials do not come at the same point in the actual curve.

quency, although light stimuli are measured in wave length in air. Light stimuli are measured sometimes, however, in terms of frequency.

The normal ear can perceive tones whose stimulus frequency ranges from about 30 v. s. to 20,000 v. s. Children, and some

adults, can hear tones of still higher frequency, up to 30,000 or more. Many persons, on the other hand, have a much shorter auditory range; some whose hearing is apparently normal in other respects are unable to hear tones above 15,000 vibrations per second.[43]

The principal component simple tones in a complex musical tone are called *harmonic partials,*[44] and their frequencies have a simple and important relationship. If we take the frequency of the lowest pitched partial, or *fundamental,* which always determines the pitch of the total tone, as 1, the frequency of the other partials, in order of rising pitch, are 2, 3, 4, and so on through the number series. If, for example, we consider the complex note of the open A-string of the violin, a tone whose pitch (the pitch of its lowest partial) is 435 vibrations per second, we will find the vibration of the several partials, from lowest up, to be as follows: 435: 870 (=2x435): 1305 (=3x435): 1740 (=4x435) and so on.

In some musical tones, and in noises generally, there are *anharmonic partials,* in addition to the harmonic series. Anharmonic partials have vibration rates which do not stand in simple numerical relationship to a fundamental. In the tone of the ordinary tuning fork, for example, there are practically no harmonic partials, but there may be an anharmonic partial, whose vibration rate is to the fundamental as 6¼ is to 1, and which may be made relatively loud if the fork is struck or bowed in certain ways.

The apparent "qualitative" difference between different tones (properly called difference of *timber*[45]) is due to the number and relative intensities of the partials present. In the tones of musical instruments, the harmonic partials are most important. In the tone of one of the longer piano strings, a whole series of harmonic partials up to the eighteenth, or higher, is present, with different intensities. In the violin tone, fewer partials are present. The

[43]The limits of pitch perception are frequently put higher, but this is due to dependence upon measurements made by the Galton whistle—an unreliable instrument.

[44]The partials, exclusive of the fundamental, are often called *overtones,* the second partial being the first overtone, the third partial the second overtone, and so on. This nomenclature is not so useful as the nomenclature in partials, since the ratios of the overtone numbers are not the ratios of their vibration frequencies. In any case, it must be remembered that the *first partial* and the *fundamental* are identical.

[45]This word is often spelled *timbre,* and given the French pronunciation. English spelling and pronunciation are preferable.

relative intensities of these partials in the series differs, however, for these two instruments, and differs for the same string also, in accordance with the exact points at which the string is struck or bowed, and in the case of the violin string, the exact way in which it is fingered. The sounding-board also reinforces the partials in a selective way, so that the character of the tone depends in part upon the nature of the wood of which the violin or the sounding-board of the piano is made, and upon its form and method of support.[46]

The harmonic partials of strings, columns of air, and vibrating plates or membrane upon which musical instruments depend, are due to the fact that these sources of sound vibrate simultaneously, not only in wholes, but in halves, thirds, fourths and so on. The anharmonic partials likewise are due to the vibration of the sources in parts not in simple ratio to the whole. The harmonic partial vibrations may be readily demonstrated in the case of a stretched string, by setting it in vibration, and then touching it lightly, exactly at the center, with a camels hair brush, or a tuft of cotton wool. The fundamental (vibration of the string as a whole) may be thus checked, but the second partial, (vibration of the string in halves) and certain of the higher partials, continue to sound. The most apparent effect is that the note "jumps an octave", since the lowest tone in a complex note determines the pitch of the whole.

By touching the string in a similar way at the point corresponding to any other integral (or harmonic) partial of the string, all the partials lower than the one corresponding to that segment (and some of the higher) are killed, and the partial corresponding to that segment becomes prominent. For example: if the string is touched at a point one-sixth of the distance from one end of the string to the other, all partials below the sixth are killed, and the sixth partial, being the lowest in pitch of those remaining, is clearly heard.

After practice in identifying the partials in a string by the method described, many of them can be discerned in the total tone while the whole series is sounding.

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[46]The different timber of the notes of two violins depends upon the different relative intensities of the partials in the notes.

Since the timber of the tone of any instrument depends solely on the number of partials present, and the relative intensities of these partials, it is possible to produce the tone of any instrument synthetically, that is, by combining the proper 'pure tones' in proper relative intensity. The important partials are harmonic in these tones, and hence a set of tuning forks, with vibration rates in ratio of 1, 2, 3, 4, etc., may be used for this purpose. In such cases, the forks should be driven electrically, in order to maintain uniform and controllable amplitude of vibration, and resonators are desirable to intensify the sounds. With such a set, the tones of the violin, flute, clarinet and other instruments, and of the human voice, may be closely imitated. In the telharmonium, a similar result was obtained by superposing the currents from a number of alternating current generators, with the proper frequency relation and sinusoidal form of alternation, in the same telephone receiver.

The partials in any complex note must be regarded as different *extents,* coincident at one end, as will be explained more fully below. If each partial be represented by a parallelogram, the length being the pitch, and the breadth the loudness, a complex note may be represented by such a figure as Fig. 11. The diagram represents also the actual scheme of stimulation of the receptors in the auditory organ.

The musical scale is based on the *octave:* the relation between the first and second partials, which have the vibration ratio of 1:2. Various divisions of the octave, made by inserting notes between these two, have been used in the music of different races, and are called *scales.* The scales used in modern western music are derived from the *diatonic scale,* in which six notes are inserted within the octave, the ratio of the notes having the relatively simple

c d e f g a b c

values of the numbers: 8: 9: 10: 10-2/3: 12: 13-1/3: 15: 16. From the diatonic scale, the true *chromatic scale* is derived by inserting additional notes between the first and second, second and third, fourth and fifth, fifth and sixth, and sixth and seventh notes in the diatonic scale. In each of these positions two notes are inserted, one, the *sharp,* having the vibration rate of 16:15 to the diatonic

note immediately below it, the other, the *flat,* having the rate of 15:16 to the diatonic note immediately above it.[47]

In the true chromatic scale, the flat of one diatonic note is always lower in pitch than the sharp of the diatonic note below it: thus, a♭ is lower than g♯. The ratio of d♭ to c♮, of g♭ to f♮, b♭ to a♮ is 25:24; and this ratio is adopted for the sharps, and 24:25 for the flats, in a secondary chromatic scale, which is more widely used than the true chromatic. In this scale, therefore, some of the sharps and flats in the true chromatic scale are used, but the names are interchanged; b♭ being the a♯ of the true chromatic scale, and vice versa. The sharps and flats between d and e, and between g and a, are slightly altered; and additional sharps and flats are inserted between g and a, e and f, and between b and c, where none are possible in the true chromatic scale.

The diatonic and chromatic scales are suitable for the human voice and certain types of instruments, such as the violin and the trombone; but if the piano and the various string and wind instruments, having fixed keys or frets, were tuned in this scale, transposition to higher and lower keys would be impossible. Moreover, the distinction between sharps and flats makes the execution of music in the chromatic scales very difficult. Hence, a simpler scale, the *equally tempered scale,* is derived from the chro-

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[47]The ratio 15 to 16 is the ratio of b to c, and also of e to f (10:10 2/3).

These ratios hold for any octave of the diatonic scale, regardless of the absolute vibration frequencies. In other words, if a certain frequency is adopted for any note in the scale, the frequencies of all the other notes are determined through the fixed ratio.

For scientific purposes, a standard scale based on a middle c (c′) of 256 v. s., is generally used. In musical practice, various standards of pitch are employed. "Low pitch" or "International pitch" is based on a′ (the note of the open A-string of the violin) of 435 v.s. This is also known as "Koenig's Normal Pitch". "High" or "Concert pitch" is somewhat above this, one standard of "Concert pitch" being based on a′ of 461 2/3 v. s. In the times of Handel and Mozart, the pitch standard was lower, a′ then being 442 v.s.

The scales based on these most important pitch standards for the octave ascending from middle c are:

		c′	d′	e′	f′	g′	a′	b′	c″
Scientific	Pitch	256	288	320	341	384	426	480	512
International	"	261	293	326	348	391	435	489	522
Concert	"	277	311	346	368	415	461	519	554

The notes in the next octave above will have double the v. s. given for the octave c′-c″: in the second octave above, four times: in the third octave, eight times, and so on. Pianos are supposed to be tuned in a tempered scale corresponding in pitch to the International pitch of the diatonic.

matic scale, and is the scale principally used for all music except that of the voice and of instruments of the violin and trombone families, when unaccompanied by other instruments.

In the equally tempered scale, the sharps and flats are identified: for example, a♯ and b♭ are in the same note: and the twelve intervals between the successive notes in the octave are equalized, so that each note has exactly the same ratio to the note of a "semitone" above it. In this scale, all instruments with keys or frets are supposed to be tuned, although the accurate tuning of pianos is practically impossible.[48]

A still further modification of the scale has resulted in the *tonal scale* used by Debussy and the "French School" of music. In this scale, only the alternate notes of the scale of equal temperament are used, the octave thus consisting of c, d, e, f♯, g♯, a♯, c. Characteristic effects, concerning the values of which the opinions of musicians differ, are obtained by the use of this latest scale.

Beats and Difference Tones

When two tones, sounded simultaneously, differ by only a slight amount in vibration rate, *beats* result. Beats are alternate increases and decreases in intensity of the primary tones, and are due to the alternate reinforcement and interference of the two sets of sound waves, their amplitudes being alternately added and subtracted. The frequency of the *primary beats* is equal to the difference between the vibration rate of the two tones. Thus, if a note of 256 and a note of 258 be sounded simultaneously, as by means of two tuning forks, the resultant beats will be 258-256=2 per second. This principle is of great value in exact tuning, since, if we have a standardized source of sound *(i. e.,* a source whose vibration rate is exactly known), and a second source, whose vibration rate is near that of the first, but not definitely known, we can sound the two together, count the beats for a definite num-

[48]The actual tuning of pianos merely approximates equal temperament, some strings having approximately diatonic relationship to each other, while others are considerably farther out of "tune" than would be necessitated by the theoretical equal temperament. For this reason, a piano composition is sometimes essentially different in effect in different keys, and pianists have not such keen pitch discrimination as those who have not played the piano. The fact that a piano does not stay "in tune" longer than a few hours, adds to the mistuning and its effects.

ber of seconds, and so determine the exact difference in vibration per second between the standard tone and the other tone.

When the rate of beats approaches 30 per second, the beats fuse into a new tone, whose pitch corresponds to the rate of the fused beats, that is, to the difference in rate between the two sounds; and this tone is therefore called a *difference tone.*[49] This difference tone, as can be demonstrated readily by drawing the curve of the combined sound wave, corresponds to a real periodic feature of the combined wave form,[50] and we can infer from this that any periodic (that is, regularly repeated) feature of a sound wave, if sufficiently emphatic (sufficiently intense), and of sufficient frequency, corresponds to a real simple tone in the total tone heard.

In addition to primary beats and primary difference tones there are secondary beats and secondary difference tones, due to the fact that a tone of given rate beats not only with a tone a few vibrations slower or faster, but also with a tone a few vibrations slower or faster than its octave. For example, the note of 256 will give not only 2 beats per second with the note of 258 (primary beat), but also 2 beats per second with the note of 514 (2x 256 + 2). These secondary beats are relatively fainter than the primary. Manifestly, when the rate of the secondary beats is increased to 30 per second or more, these also will form a new tone (secondary difference tone). Beats and difference tones of the third, fourth and higher order have been reported by some observers.

Since most actual tones are complex, that is, contain many partials, the possibility of beats and difference tones between two such tones is complex. The fundamental of one may beat with the fundamental or higher partial of the other, or the higher partial of one may beat with a higher partial of the other. Even in the

[49]Difference tones obtained by bowing two strings of a violin simultaneously are known as Tartini's tones.

[50]In the case of a difference tone, although there is, in the complex stimulation, a real periodicity corresponding to the pitch of the difference tone, the analysis of the complex wave gives no simple stimulus curve corresponding to it. The combination of two simple pendular air waves in these cases, gives a complex wave which is the stimulus of a complex note in which there are *three* simple tones. This fact constitutes one of the difficulties in the way of accepting the Helmholtz ''selective resonance'' theory of auditory stimulation.

case of a single source of sound, such as a bell, or the human voice, the partials of which are not completely harmonic, these partials may beat with each other, producing the rapid ullulations which are peculiar to these sources.

In musical practice, harmony and discord are of great importance. Two tones harmonize perfectly when the partials of both are harmonic, and every partial in one coincides with a partial of the other. In this case there are no beats. A tone will harmonize perfectly with its octave, or with any other note whose fundamental is an harmonic partial of the first note. The interval which ranks next in harmoniousness to the octave is the "perfect fifth" of the diatonic scale, e.g., the interval c-g, or e-b, with ratio 2:3. Next comes the major third, represented by c-e, f-a, or g-b, with ratio 4:5. In general, the smaller the ratio numbers of two notes, the more nearly perfect their harmony, as shown by the intervals just mentioned, and as may be further illustrated by comparing the perfect fifth c-g, with the fifth d-a, the ratios of which are 2:3 and 27:32 respectively. This rule does not hold invariably, however, for the fourth, ratio 3:4, is less harmonious than the major third, 4:5.

Very imperfect harmony, in which there is not only failure of coincidence among the partials of the two (or more) tones, but also beats among the series of partials, is called *discord*. Less pronounced degrees of discord are called *dissonances*. Dissonances are not necessarily unpleasant, and modern music employs not only dissonances, but even discords, to produce its effects. Habit-formation has a large share in determining these effects. To a hearer accustomed to music in which few dissonances are employed, dissonant music is highly disagreeable. But with continued listening to such music, the hearer may come to prefer it to the more harmonious music.

The auditory receptors are "hair cells": epithelial cells with cilia attached: located on the basilar membrane of the cochlea. Concerning the method of stimulation of these cells, a number of theories have been evolved, but none is conclusive. These receptors are arranged in two parallel series—a double row and a triple row—extending the length of the basilar membrane. From the psychological facts, we may tentatively infer that the stimulus

of a tone excites all the cells in a certain length of the receptor series, the length being the greater the lower the pitch; and that all the extents stimulated coincide at one end (the vestibular end) of the series. The highest perceptible tone, therefore, stimulates only the cells at the extreme end of the series; and all tones which excite the whole series of cells have a maximally low pitch.

This hypothesis agrees with all the psychological facts, and with the few known physiological facts.[51] The destruction of receptors at the vestibular end of the series produces deafness (anacusia) for high pitch, but not for low pitch. Presumably, in such cases, the low tones do not sound as low as they would if the whole receptorial series were intact, since the total number of receptors

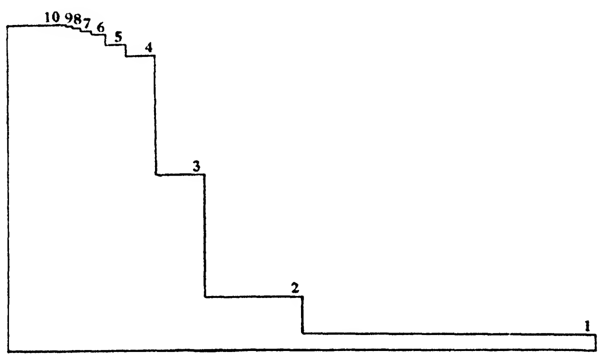

Fig. 11.—Scheme of a complex tone. This scheme is drawn from Miller's measurements of the intensities of the partials of the organ-pipe tone, whose wave-form is represented in Figure 10. The abscissae represent the pitches of the partials, and the ordinates represent the sums of the physical intensities. The scheme, therefore, represents the relative intensities of stimulation of the auditory receptors, from the vestibular end of this series (left) to the end of the stretch stimulated by the given note.

stimulated is less. In inflammatory conditions of the middle ear, the apparent pitch of sounds may be changed in one ear as compared with the other (a condition known as *diplacusia binauralis dysharmonia)*: the change in at least one carefully observed case having been approximately a semi-tone (ratio 15:16.) In such a case it is possible that the change in the density of the fluid sur-

[51]The existence of "tone-gaps" and "tone-islands" might be supposed to militate against this theory; but these are pretty clearly due to abnormal conditions of the mechanism for transmitting sounds to the internal ear. In the case of a tone-gap the patient is anacusic (deaf) to sounds of a certain range of pitch, although sensitive to sounds above and below the range. In the case of a tone-island, two such gaps enclose a short sensitive range.

rounding the basilar membrane changes the length of the portion of the receptor series excited by a stimulus of a given frequency.

The structural characteristic of the cochlea which appears to support the extensity theory consists in the form of the tectorial membrane, which overlies the receptors. This membrane increases in width and thickness from the end nearest the middle ear to the end nearer the vertex of the cochlea. While the structure and attachments of this membrane are not such as would lend themselves to "resonance" or sympathetic vibration, the progressive increase in inertia of the membrane from one end to the other does suggest the functions demanded by the extensity theory. The parts of the membrane which could be set in motion by waves of high frequency would also be set in motion by waves of slower frequency.

On the psychological side, we have the following facts which support our hypothesis:

First: high pitched tones are heard as less extensive, smaller, than low pitched tones. If one listens to tones of varying pitch, with as little prejudice as possible for the common terminology, one finds that the bass notes are describable as large, bulky: the treble notes fine, thin, and so on. Obviously, these are metaphorical terms, used to convey the similarity between the pitch variation and the variation in size of tactual and visual objects.[52]

Second: the apparent pitch of any complex tone is the pitch of its lowest partial. The reason for this can be seen by referring to Fig. 11 much more easily than it can be explained in words.

Third: a loud low tone will drown out a faint high tone, but a high tone, however loud, will not interfere with the perception of a faint low one (provided "beats" and other secondary effects are excluded).

Fourth: there is an essential difference between the "musical ear" and the "unmusical ear." An individual who has an "unmusical ear" judges pitch differences in a rough way, as if mere gross sizes of objects are directly compared. On the other hand,

[52]The origin of the terms "high" and "low" as applied to pitch is obscure, but probably comes from the observed behavior of the throat in singing. The Greeks used the two terms in exactly the opposite way, the notes of the long strings of the harp being "high," and the notes of the short strings "low." Apparently this designation was due to the position of the hand in plucking the strings.

the person with a musical ear judges in a more exact way, as if he noted the point to which (as represented in the scheme) each tone extends. In extreme development of the "musical ear", it reaches what is called *absolute pitch*, which is the ability to recognize at any time the approximate pitch of any note heard, regardless of the relation to other notes. In cases of ordinary musical proficiency, it is possible to tell whether a note sounded is of the pitch of a note heard from several minutes to several hours before, or whether the two differ even slightly.

Anacusia for high pitches, or reduced sensitivity to high pitches, with little apparent effect on the audition for low pitch, is of frequent occurrence. Individuals suffering from the defect may be "normal" up to 1,000 vibrations per second, and may even be hypersensitive to tones in the lower part of the usual range (below 128 v.s., for example); yet they have difficulty in understanding words, and especially whispers, because the discrimination of consonants depends upon the hearing of the high partials in the vocal sounds. Apparent dullness of children in school is sometimes due to this cause, and inability to understand whispers easily is always a sufficient reason for having the hearing tested by a psychologist. A child recently examined in the Johns Hopkins Psychological Laboratory had been pronounced "feeble-minded" by his teacher, and "normal" in hearing by an ear specialist; but was found, on careful test, to be seriously defective in the upper auditory range, and mentally above normal.[53]

In some cases of anacusia for high pitches, the sensitivity for low pitches is even greater than that of the "normal" ear. These cases are not helped by the microphone devices, now much used by deaf people, because these devices intensify the low pitched notes relatively more than the high pitched, and so increase the difficulty of hearing language. In another type of deafness, in which the anacusia extends also to low pitches, these devices are beneficial. A third type of deafness, in which there is anacusia for low pitched tones, with less or none for the higher pitches, might be supposed to exist, on the basis of some theories of audition.

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[53]It should be explained that the reason some ear specialists do not detect such conditions is that they have no instruments for the purpose, and in many cases are not interested in the condition, as nothing can be done for it therapeutically.

CHAPTER IV

THE SOMATIC, VISCERAL AND LABYRINTHINE SENSES

§1. The dermal senses.

The modal senses of touch, pressure, warmth, cold, pain and tickle have bipolar nerve cells as receptors. The cell bodies of these receptors lie either in the spinal ganglia, close to the spinal cord, or in certain ganglia of the head, adjacent to the brain stem; and the dendrites of the receptors terminate in the skin, the subcutaneous tissues, and the mucous membrane of the mouth, the upper part of the gullet, and the anus.

Each of these senses apparently functions for sense data of one quality only, just as does the auditory sense.

The physiological separation of the tactual, rhigotic, thalpotic and algetic senses is sharply shown by certain cases of disease or injury of the spinal cord or brain stem. In some such cases, dermal areas are found which are totally insensitive to pain, although sensitive in the other three modes. In other cases, thalpotic sensitivity alone is lost. In other cases rhigotic sensitivity alone may be lost. In various cases, dermal areas are found in which two forms of sensitivity are lost, and the other two retained.

Tickle

The adequate stimulus for *tickle* is very light contact with the skin (or mucous membrane) or with hairs, and is intensified by movement of the contact over the surface. The term *tickle* is here applied to sense data of a distinct quality, and does not refer to the profound organic processes and experiences which are set up by stimulation of the subcutaneous tissues of the trunk, as by pressure in the region of the ribs or abdomen.

The reaction set up by the tickle-stimulus may be violent as compared with the stimulus intensity, and usually provokes the movement of rubbing the part of the skin tickled. It has been

suggested that the development of this reaction has been of service to man as a protection against insects, since the stimulation produced by an insect brings about the reaction which would destroy it or brush it away. Tickle is exclusively a characteristic of the body itself, and is never perceived as in an external object: tickle-perception is strictly a form of auto-perception. Very little further can be said about tickle at present, since in investigation of dermal sensitivity it has usually been neglected, or confused with touch.

Epicritic and Protopathic Sensitivity

Early investigations of touch, pressure, warmth and cold resulted in serious confusion, which has been cleared up by the clinical and experimental work of Henry Head and his co-workers. It is now known that there are two sets of sensory mechanisms, one the epicritic, functioning for the perception of touch or contact, mild warmth, (from 37° to 45° C.),[54] and mild cold, (from 37° to 20° C.): the other, the protopathic, functioning for pressure, pain and the higher intensities of heat and cold, (above 45° and below 20° C.). In certain cases of disease or injury of the peripheral nerves, protopathic sensitivity alone, or epicritic alone, has been found on certain areas of the skin, and thus each has been studied in isolation. Some areas, such as the glans penis of the male (and apparently the linings of the sinuses, or cavities in the skull bone which connect with the nasal cavities) normally possess only protopathic sensitivity.

Protopathic sensitivity is autoceptive. Through its mechanism, when acting alone, we perceive pressure, pain, heat and cold, as conditions of the skin or mucous membrane themselves, never as properties of external objects. Epicritic sensitivity, on the other hand, is heteroceptive: mild warmth and coolness and the tactual quality (contact) are felt as properties of objects touching the body surface. When both systems are active together, on the same area, the protopathic qualities may be perceived as external, or the epicritic as organic.

Protopathic sensitivity is definitely localized. Appropriate stimulation at certain points in the skin produces perception of

[54] Assuming the temperature zero of the body to be at 37°.

heat; at other points, cold; at others, pressure; and at others, pain. At other points no response can be obtained. It is assumed, therefore, that there are specialized receptors for each of these sense-data. Epicritic sensitivity, on the other hand, is only in part localized. Stimulation of any point on the skin, by means of a stiff bristle, will produce touch, although the sensitivity is greater at some points than at others. Epicritic warmth and coolness seems to be localized in a general way within small areas. Within one of these "warmth areas" there are always to be found points at which the epicritic warmth can be aroused, although at times there may be other points at which it can not be aroused. Similarly, there are cool areas, within which the epicritic coolness can be felt always at some points, although perhaps not at others. There are other areas within which the epicritic cool never can be felt, and areas which are immune to warmth. The exact localization of the sensitive points within the areas varies from time to time, however, so that we can speak of the localization as *areal* only, not as *punctuate*.

In contrast with the actual localization of epicritic and protopathic sensitivity, the perception of locality is relatively acute through epicritic sensitivity, and relatively vague and inaccurate through protopathic. On areas supplied with protopathic sensitivity only, the location of stimulated areas can be identified only in a vague or general way.

Since there is no epicritic pain to be confused with the protopathic pain, the punctuate localization of pain sensitivity can be demonstrated on the normal skin, by stimulating with a fine needle. At some points light pricking with the needle point gives distinctly the pain quality: at others the needle can be thrust into the skin without any pain.

Prior to Head's work, it was believed that warmth and cool sensitivity were localized punctuately, just as pain was found to be. This belief was due in part to the ignorance of the distinction between protopathic and epicritic sensitivity, and in part to faulty methods of research. Especially careful technique is needed in conducting research upon the dermal senses, because they are maximally subject to "suggestion" effects. That is to say: Reactions primarily initiated through these receptors may be influ-

enced profoundly by the stimulation of other senses, and by ideational reactions occurring at the same time, or just preceding. An instance of this "suggestion" effect which most men have experienced is the "electric" effect of a lock of a girl's hair brushing lightly against his temple: far different from a mechanically similar stimulation produced by a tuft of cotton.

In spite of the functional difference between the epicritic and protopathic sensitivities, it is not necessary to suppose that there are four temperature senses. The differentiation between warmth-sensitivity and heat-sensitivity, and between cool-sensitivity and cold-sensitivity is to a large extent peripheral. In diseases of the spinal cord and of the brain, it is found that if warmth-sensitivity is affected, heat-sensitivity is also affected; and that cool-sensitivity and cold-sensitivity also are affected alike. Either of the thermal senses may be lost, on certain areas, through injury to the cord or brain, without affecting touch and pressure, or pain; and similarly, either of these latter may also be disturbed. The whole matter of the relationships of these senses is exceedingly complicated, and no final conclusion is yet possible.

Thermal Stimulation

The normal rhigotic stimulation is the loss of heat from the skin, and the normal thalpotic stimulation is the conduction of heat to the skin. Heat, physically considered, is molecular vibration, and may be conducted by transference of the vibrations from molecule to molecule. This sort of conduction is supposed to occur when a hot or a cold object is applied to the skin. "Radiant heat", which may become a stimulus when a hot object is placed near the skin, is not properly speaking "heat" at all, until it strikes the skin. The molecular vibrations of the hot object set up ether vibrations mostly of wave lengths greater than that of the visible spectrum, and these ether vibrations, transmitted to the skin, excite in the skin "heat", *i. e.,* molecular vibrations of a certain sort. Similarly, when ice is brought near the skin, ether waves, caused by the heat in the skin, radiate to the ice, and are there transformed into heat.

Heat as such is not a sensory stimulus under ordinary condi-

tions. The conduction of heat to the skin, or the checking of the conduction away, may be the stimulus for "warmth", and the conduction away in excess of a certain rate, is the stimulus for "cold".

The rate of conduction in either direction required to stimulate the receptors is variable, being subject to adaptation. Under normal conditions, there is a *physiological zero* for any given point on the skin, and the cooling of the skin below that temperature, if the cooling is sufficiently rapid, produces rhigosis; the raising of the temperature above the physiological zero-point produces thalposis. This physiological zero is usually assumed to be about 37° C. (98° F.), but is subject to adaptation, and differs in different parts of the body at the same time.

If two dishes of water are provided, one feeling distinctly cool, the other icy cold, to the finger; and if the finger is kept in the colder water for some seconds, and then transferred to the less cold, the latter will feel warm. Conversely, by adaptation to hot water, water which is normally warm will feel cold. Adaptation may be carried even to dangerous extremes. In one case, under a physician's order, a patient's hand was kept for several hours in a bowl of water to be maintained at a temperature "as high as the patient found comfortable". The temperature was slowly raised during this period, and the skin scalded from the patient's hand without the least discomfort. A frog may be killed by heat, if placed in cold water which is subsequently raised in temperature at a slow rate, without the frog's showing the least evidence of unpleasant stimulation.

Hair Sensitivity

Although the skin and hair bulbs in general function similarly in tickle and touch perception, there is a difference in their neural mechanisms, and in certain cases of nervous disease, trichesthesis may be lost without disturbance of skin touch, and converse cases have also been reported. The receptors ending in the hair bulb may be stimulated by very light contact with the hair, which acts as a lever to increase the pressure in the bulb.

Fusions of Dermal Sense Data

It has been claimed that the different modes of dermal sensitivity in reality form a single sense, since the data of these senses fuse with one another, just as do the four tastes with each other. It is true that fusions of touch and warmth, touch and cold, are common occurrences. Tickle and heat also fuse in the form of "itch". The two thermal qualities, however, never fuse with each other: there is no such thing as cold-warmth. Although the theory that heat is a fusion of cold and warmth was seriously maintained some years ago, the grounds for the theory have been swept away by Head's work. Since these are manifestly of different modes, the fusion of touch with each of them does not prove that touch belongs to the mode of either. For the present, therefore, it is best to consider the dermal sense as being six distinct modes.

Inadequate Stimulation of the Dermal Senses

It is said that a sudden hot stimulus may excite the cold (protopathic) receptors, giving rise to the "paradoxical cold" perception. This perception is often caused by plunging the hand or foot into a tub of hot water, not previously known to be hot. Whether this is really a case of inadequate stimulation, or a case of failure to recognize a sensory quality, is open to discussion. Intensive heat is usually fused with some degree of pain, and the occurrence of the heat without the pain, in the first moments of stimulation, makes the recognition more difficult. It is interesting to note that savages who are totally unfamiliar with ice and snow, report on first contact, that it "burns" them, although there is no evidence for inadequate stimulation of the heat receptors in such cases.

Tickle may be caused by physiological conditions of the skin without contact. Heat also may be physiologically stimulated. The occurrence of the two fused in itch has been already noted. Touch, tickle, pressure and pain may be excited by electrical stimulation.

§2. Palmesthesis

Whether there are special receptors for palmesthesis (the vibration sense) or whether receptors for other somatic senses also

function palmesthetically, cannot be determined at present. Vibration can be perceived apparently through receptors terminating in the skin, subcutaneous tissue, and the bones, or membrane covering the bones. The muscles also may be palmesthetically sensitive, but this is not certain. The stimuli are molar vibrations of the same type as the auditory stimuli, of a frequency range which overlaps the audible range, beginning somewhat lower, but not extending as high as the latter. The exact limits have not been determined.

In testing palmesthetic sensitivity, it is necessary to take precautions that the stimulation shall not be transmitted to the auditory mechanism, either through the air or through the bones of the skeleton. Confusion of auditory and palmesthetic qualities may easily occur; but the separation of the senses is certain. Totally acusic individuals are able to perceive vibration, through the fingers or other parts of the body, and to distinguish the extensity (rate) of these vibrations. Deaf persons may derive satisfaction from palmesthetic stimulation obtained by touching a violin or other instrument while it is played, and may be able to recognize and distinguish musical compositions palmesthetically. It is probable that in such discrimination, the rhythm of the stimulus is at least as important as the extensity ("pitch") differences.

Palmesthesis has been frequently classified under touch or pressure, and vibration as perceived supposed to be a series of touches. That this assumption is not correct is evident from the facts that: (1) palmesthesis may be present on areas of the body from which touch and pressure have been lost through disease of portions of the nervous system: (2) palmesthesis is present in parts of the body (*i. e.*, the bones) in which neither touch nor pressure is present even in normal conditions: and (3) vibration can be distinctly perceived at rates of vibration far above the rate at which touch stimuli fuse into continuous touch (analogous to the fusing of flashes of light, at rates above the critical frequency).

The most convenient means for the demonstration of palmesthesis is by setting a light-weight tuning fork in vibration at low amplitude, and pressing the end of the fork-stem on the skin of the hand or foot, selecting the fleshiest parts to avoid transmission to

the bone. Forks of vibration rates below 500 v. s. are most satisfactory.

§3. The sexual sense.

Receptors terminating in the glans penis of the male, and in both external genitalia and vagina of the female, function in the perception of a sense datum whose stimulation is physical contact, but whose quality seems to be distinctly different from that of dermal touch. The conclusion that the sense is a specific one is supported by the claims of some histologists that the genital receptors differ from the termination of receptors for dermal touch. This claim is, however, not undisputed. Observation is rendered difficult by the fact that the reactions caused by genital stimulation produce organic sense data in other parts of the body, which are both extensive and intense, and which conjoin with the genital data so intimately as to make qualitative discrimination difficult. It is possible that the so-called genital quality, if entirely abstracted from these organic qualities, is nothing more than ordinary protopathic pressure. But the greater probability is that although more closely akin to protopathic than to epicritic quality, the sexual quality is *sui generis*. Whether the quality in the male is different from that in the female is a question to which the answer is at present conjectural.

§4. Kinesthesis.

Kinesthesis, or the awareness of movement, is a complex process depending peripherally upon receptors in the striped muscles, in the tendons, the joint surfaces, and the joint capsules. The dermal sensitivity also cooperates with kinesthetic sensitivity, since movement of the parts of the body, by changing tensions on skin and subcutaneous tissues, stimulates receptors there. But the rôle of dermal and subdermal sensitivity is adventitious, and not essential, to kinesthesis.

The terms *proprioception* and *proprioceptive* are sometimes applied to kinesthetic sensitivity and the kinesthetic mechanism alone, since this form of sensitivity is sometimes literally perception of one's self, and not of external objects. As we have seen already, tickle, pressure, pain and protopathic heat and cold are as really proprioceptive as is kinesthesis; and the same is true of

the visceral sensitivity (cenesthesis); whereas on the other hand, the kinesthetic mechanism has also certain non-proprioceptive functions, as described below. The term proprioceptive is therefore an unfortunately confusing one for psychology, and its use is not to be recommended.

It is not certain that there is more than one kinesthetic quality. Movement is the real datum perceived, and the various perceptible movements are complexes of different intensities and extensities, but it is not obvious that they are complexes of different qualities.

Evidence of the function of the joint surface in kinesthesis is found in the fact that movement of an arm or leg is more accurately perceived when the moving joint surfaces are pressed together, than when they are pulled apart. The functioning of the muscles might be inferred from the rich supply of afferent nerve fibers which connect with the muscles, and the inference is conclusively corroborated by the *ataxia* which follows interruption of these fibers. Ataxia is the condition in which movements of the limbs or trunk are poorly coordinated and are perceived with inaccuracy.

The kinesthetic mechanism seems to have other functions in addition to kinesthesis. One of these, which is distinctly not proprioceptive, is: the perception of *resistance* offered by external objects. This function, whether exercised in pressure against an object, or in lifting a weight, is an important aid in our acquisition of knowledge of the outside world. Kinesthesis is also an essential means for the development of the perception of space relations, so that its "proprioceptive" function is in many respects a minor one.

Other functions of the muscular division of kinesthesis are the experience of strain and fatigue, with their after-effects of relaxation and relief. These, while functions of the mechanism which is conveniently designated as kinesthetic, are strictly cenesthetic ("proprioceptive" in the legitimate sense of the word), and will be described under organic sensitivity.

§5. Bodily feelings.

The data of the organic senses, although complexes of sentienda, are commonly called *feelings.* This term was formerly ap-

plied to tactual, thermal and kinesthetic data, and is very frequently applied to tickle and pain, since these are truly organic. We shall use the word "feeling" here as strictly synonymous with *organic sense data,* that is to say, as designating perceptible conditions of the body or organism itself.

Organic sensitivity probably includes many different modes, but their discrimination is exceedingly difficult. Strictly speaking, the sexual sense; the dermal pain and tickle senses; and the protopathic pressure, heat and cold senses, are organic senses; and our inclusion of these under different heads is to be understood as a mere deference to custom, defensible only on didactic grounds.

The Pain Sense

The so-called dermal pain sense is merely one detail of a more general pain sense, which has receptors terminating in almost all tissues of the body. There are apparently a number—perhaps a large number—of pain qualities, including the quality which is observed on the skin, and the *ache* which subcutaneous tissues and the teeth sometimes have. The peculiar "cutting" or "sticking" pain referred to the heart, the tearing pain which sometimes follows the drinking of cold water in the morning, the gripes of intestinal colic, the pains of blinding light, intense noises, and overstimulation of the genital sense, are either distinct qualities or are complexes embodying distinct qualities other than the common ache and pain. Many complex pains include data of other modes—heat, cold, pressure, kinesthetic, and organic data. In some cases, the pain is so intimately combined with another quality, that analysis of the former is difficult. This is the case with "blinding pain" of the retina, which in the normal eye occurs only fused with intense light. In certain cases where vision has been completely lost, however, the characteristic "blinding" pain alone is produced by intense light stimulation.

The relation between heat and certain forms of pain is peculiar, the two qualities sometimes being difficult to distinguish. The boring of a dentist's drill into a sensitive tooth produces an intense feeling which is perhaps a fusion of heat and pain; or else is a quality of pain hardly distinguishable from heat. Cold, on the

other hand, is often qualitatively confused with ache, perhaps because cold-stimulation frequently produces ache. I have suggested earlier the possibility that pain and ache are really high intensities of heat and cold respectively, and this suggestion is by no means an irrelevant one.

Pain is perceived in general when the response of any receptor to an adequate or inadequate stimulus is sufficiently intense. It would appear, therefore, that there is no specific receptor for pain. It is reported by various observers, however, that at certain points in the skin and conjunctiva, light stimulation, by mechanical pressure, usually produces pain, but no other sense quality. These observations may be erroneous. It is not improbable that these responses in the skin are due to receptors which also function for the tickle sense and in the conjunctiva to touch receptors, the limits between the stimulation which produces tactual quality and that which produces pain being so small as to be overlooked. But if it is true that a limited group of receptors are actually so constituted that any response thereof is a pain response, this does not conflict with the general fact that pain perception is the function of receptors of all types.

Over against the receptors which perhaps respond to pain only, we must set receptors, such as those for epicritic warmth, which cannot be overstimulated. Application of intense adequate stimuli, or inadequate stimuli, apparently never produces intense warmth (heat), but these receptors cease to function entirely under such stimulation.

The analysis of pain sensitivity is complicated by the fact that analgesia of bodily areas, dermal and internal, may exist without anesthesia for any other qualities, and the converse condition also occurs. This, presumably, is due to the fact that the routes of conduction in the spinal cord and brain-stem for the neural impulse involved in pain perception are separate from those for other afferent impulses from the same body areas, and the interruption of one of these routes may occur through disease or injury, without affecting the other. The whole matter of pain sensitivity is obscure, and final conclusions must wait upon further experimental and clinical work, for which the discoveries of Head have pre-

pared the way. The literature of the subject for the period preceding Head is full of confusing and contradictory observations, on which it is now necessary to look with considerable skepticism.

Alimentary Sensitivity

Aside from the gustatory and dermal sensitivity regionally connected with the mucous membrane of the mouth and anus, the alimentary canal has several forms of sensitivity. Of these the most conspicuous are hunger and thirst. Thirst is a condition of the mucous membrane of the pharynx and the upper part of the gullet. Certain receptors whose dendrites terminate in this region are probably stimulated by the reduction of the water content of adjacent epithelial cells. When the water content of the organism needs replenishing, these cells are affected early, and thirst is experienced; and also reactions effective in obtaining renewed water supply are brought about. That the thirst, while normally an index of a general systemic need, is itself a local condition, is demonstrated by the fact that local dryness produced by dry or dusty air, or by the application of chemicals (such as salt) which extract water from the tissues, when the general system is adequately supplied with water, gives rise to thirst which may be removed by the local wetting of the mucous membrane.

Conditions of other tissues similar to thirst are apparently set up in advanced stages of water deprivation, and in febrile diseases. These conditions, however, are not called thirst.

Hunger is apparently a condition of the mucous membrane of the stomach, although the details of stimulation of the receptors are not understood. Hunger normally occurs only when the stomach is empty, (although it may occur when the stomach is full) and it has been found by Cannon, Carlson and others, that in some persons the hunger increases and decreases rhythmically with periods of a number of seconds; and that this periodic fluctuation of the hunger is approximately synchronous with tonic contraction and relaxation of the empty stomach. Further details concerning hunger will be given in Chapter XV.

Nausea is a common stomach condition which leads in some cases to stomach contraction with relaxation of the gullet. Nausea

may be induced in various ways; by direct stimulation of the stomach, by stimulation of the root of the tongue or of the region of the juncture of the gullet and pharynx, and by stimulation of the semicircular canals of the head. The actual stimulus, in other words, is produced in the stomach as a result of nerve currents whose primary origin may be various. The "settled" condition of the stomach, after vomiting has occurred, is apparently as distinctly perceptible a condition as is the preceding nausea.

Appetite for food is said to involve, in addition to desire, a specific "food-feeling," distinct from hunger. This feeling occurs, even when one is not hungry, in the smelling or tasting of good food; but it is neither the odor nor the taste. When appetite is aroused, and food taken into the stomach, a distinctly different feeling of *satisfaction* is usually obtained. These feelings are commonly accompanied by pleasure, but are distinct from the pleasure.

Fullness of the stomach, and fullness of the small intestines, are distincly perceptible, and definitely due to a certain degree of stretching of the coats of the stomach and intestines. *Emptiness* is an equally perceptible condition, and *relief* after fullness and after emptiness is also recognizable. The fullness of the rectum, which is the usual sign of the need for defecation, and the relief which follows normal defecation are apparently qualitatively distinct from the fullness and relief of the stomach and small intestines.

Pain may be aroused in any part of the alimentary tract, but apparently only by intense muscular contraction, or chemical stimuli. Cutting and other mechanical injury is without effect, although the peritoneum and pleuræ which cover the stomach, intestines and other entrails, and line the abdominal and thoracic cavities, are extremely sensitive to mechanical injury. Touch and pressure sensitivity are absent from the stomach, and warmth cannot be stimulated in that organ except by chemical means (alcohol, for example), not by thermal stimuli.[55]

[55]The heat felt after drinking too hot a liquid comes not from the stomach, but from the peritoneum, being transmitted through the stomach wall without affecting it sensorily. The mouth and upper part of the gullet, of course, are sensitive to thermal stimulation.

Genito-Urinary Feelings

Fullness of the bladder, and relief after urination, are data of distinct qualities. The contraction of the urethra and sphincter muscles of the bladder are also distinctly perceptible. Intense pain may be aroused in these organs and in the kidneys, by mechanical and chemical stimulation.

In addition to the specific genital quality which has been mentioned under another heading, there are intense feelings, apparently of complex quality, which are localized in the external and internal genitalia. Sexual appetite and sexual satiety of a localized sort are among them. These are so conjoined with pleasure and other general bodily feelings that the clear discrimination of the specific sex feelings from the total cenesthesis is almost impossible.

Cardiovascular and Respiratory Feelings

The normal contractions of the heart are perceptible, but whether this perception is actually cardiac or peritoneal cannot be decided. Intense contractions are distinct, and the sudden checking of the heart produces a perception of an intense, but indescribable sense quality. Cardiac pain is usually of the "sharp" variety, although literal "heart-ache" is not impossible. The contraction and relaxation of the muscular coats of the blood vessels contribute a vast mass of sensory data, which is of considerable importance for our conscious experiences. The "feeling of excitement" and the "feeling of depression" are very probably conditions of the general vascular system (heart and blood vessels). The sudden flushing or blushing of the skin, due to relaxation of the capillaries, is as perceptible organically to the blushing individual as it is visually to the spectators.

The choking feeling in the throat frequent in rage, fear and sudden joy may also be classed as cardiovascular. It is supposed to be due in part to the swelling of the thyroid gland by increased blood supply.

In addition to the muscular feelings associated with the process of respiration, there are certain feelings dependent upon the process, which, however, may be really vascular rather than

strictly respiratory. The feeling of *stuffiness* in a close room is distinguished from the thermal and olfactory sense data accompanying it. The feeling of *suffocation* which follows prolonged holding of the breath is perhaps qualitatively identical with "stuffiness." The feeling of respiratory *relief* which is produced by the resumption of breathing, and also by the breathing of "fresh" air after "close" air, is distinguishable from other relief feelings.

Vestibular and Ampullar Senses

There are two groups of receptors, both hair-cells similar to those of the auditory sense, located in the *vestibule* of the inner ear, and the *ampullae* of the semicircular canals, which connect with the vestibule. The vestibular receptors have been supposed to have a function in noise perception; but it is now known that they, as well as the ampullar receptors, have no auditory function whatever. Much speculation has been indulged in regarding the function of these receptors. They have been supposed to be organs for the direct perception of motion, but this supposition has no foundation. It is not even certain that these receptors have any sensory function at all, although they are commonly referred to as "sense organs," and in the opinion of the author, are organic sensory mechanisms.[56]

The primary function of the vestibular and ampullar mechanism is one with which sense perception is not necessarily connected, namely, the control of bodily movements and of eye movements. The adequate stimulus for the ampullar mechanism is movement of rotation of the head. The adequate stimulus for the vestibular organ is change of position of the head, either rotary or linear. These stimulations reflexly produce change in the tonus of various groups of skeletal muscles: changes which are demonstrated in bending and twisting of the body, and in eye-nystagmus, and which assist in compensating for the head movements and thus in maintaining equilibrium, and in facilitating visual coordination.

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[56]Not even the physiologists who designate the vestibular and ampullar receptors as "sense organs" assume a sensory function, as psychologists use the term "sensory", namely, as applying to perceptual processes or mechanisms. The physiologists use "sensory" as equivalent to "afferent", with no implication as to experience.

As a result of these changes in the striped muscles, movements, both real and illusory, are perceived. Along with the striped muscles, the visceral muscles are affected, one indirect effect of strong stimulation of the ampullar and vestibular receptors being *nausea.*

In addition to the illusion of motion and the nausea, produced indirectly by such stimuli as rotation, when sufficiently violent and prolonged, there is a feeling of a peculiar quality, localized vaguely in the head, which is probably due to a direct sensory function of the vestibular or ampullar apparatus, or both. The term "vertigo" is unfortunately used to cover this feeling, the illusory movement and the nausea, indiscriminately. We might perhaps call this feeling *giddiness,* if we should refuse to apply this term to the other two phenomena confused with it under the term vertigo.

Fatigue

The term fatigue is used to indicate three different phenomena: (1) The exhaustion of an organism, or part of an organism, and the consequent impairing of its functional efficiency. Such exhaustion is usually brought about by the continuation of the function itself. Thus, if a weight be lifted repeatedly as rapidly as possible, by means of a finger, the height and frequency of the movement soon begins to diminish, and finally the movement becomes almost impossible.[57] The mechanism, in short, has become exhausted. (2) The term is also applied to adaptation processes, such as those occurring in vision, which are probably not exhaustion effects at all. (3) Fatigue, in the sense in which we shall use it here, is a condition of the striped muscles, apparently due to the presence of certain toxic substances, of which the most important is lactic acid (or certain lactates), with possibly some effect of carbon dioxid and acid calcium phosphate: substances which are produced by muscular activity. It is also claimed that other toxic substances produced in the muscles are effective. These

[57] This is the *ergographic* test. The exhaustion is principally in the central nerve cells (in brain and cord), and in the juncture between efferent nerve fibers and muscle fibers. The afferent and efferent nerve cells can practically not be exhausted, and in the ergographic test, the muscles themselves have suffered comparatively little loss of contractile ability.

substances are carried by the blood stream throughout the organism, and produce their effects, therefore, not only in the muscles where they originate, but in the musculature generally. On this account, work done by a limited group of muscles, for example, by the legs in working a pedal-machine, produces not merely fatigue of that muscle group, but of the whole muscular system.

The toxic fatigue substances probably act as stimuli to the receptors terminating in the striped muscles. This part of the so-called "kinesthetic" sensory mechanism has accordingly a range of non-kinesthetic organic functions even greater than that which we have above indicated. The toxic substances are normally destroyed by oxidation in the blood, although in extreme fatigue they may be excreted unoxidized by the kidneys and sweat glands. Epinephrin, or adrenin, which is secreted into the blood by the adrenal glands, apparently is capable of neutralizing the effect of these substances, or of hastening their oxidation, and so is a powerful agent in the counteraction of fatigue. The phenomenon of "second wind" is now believed to be largely due to the increased production of adrenin under conditions of extreme fatigue and emotional excitement. The condition sometimes described by the misleading term *mental fatigue* is usually a condition of exhaustion or toxic poisoning of the nervous apparatus, occurring without a large amount of true fatigue. Some actual fatigue, especially of the vocal muscles, frequently occurs in "mental fatigue," but the most characteristic feelings in such conditions are depression and excitation. In cases of decided real fatigue, the so-called "mental fatigue" effects may also be present, and may be due principally to action on the nerve cells by the lactic acid and other substances which produce the muscular fatigue feeling.

If the term "fatigue" is to be retained in application to exhaustion and toxic effects in the central nervous system, and to the effects of their condition in psychological efficiency, it would be better to distinguish them as "central fatigue" and "central fatigue" effects, from the condition of fatigue-feelings to which the term *muscular fatigue* may be applied. Central fatigue must, in the future, receive a large amount of attention from experimental psychology, on account of the practical importance of the

topic, in connection with school, commercial and industrial operations.

Pleasantness and Unpleasantness

These feelings have been the subject of much controversy, and many hypotheses concerning them have been applied. They have been considered as characters of sense data, on a par with quality, intensity and extensity: and they have been supposed to be strictly sexual sense data. Both of these theories may be excluded now. Pleasantness and unpleasantness are bodily feeling of a general rather than a localized nature, and the discussion of their nature and laws will be taken up in a later chapter.

Without doubt there are a great number of bodily feelings for which we have no names, and concerning whose conditions we know little. Observation on them is exceedingly difficult on account of our lack of means of control. Some of these vague feelings, which enter into the more definite emotional complexes, will be discussed later.

CHAPTER V

SOME DETAILS CONCERNING SENSORY CHARACTERS

§1. The relativity of sense data.

In the preceding chapters, the fact has been brought out that the intensity of sense data is not a fixed or absolute quantity, but is relative to the perceiving mechanism. The brightness of a light, for example, depends upon the adaptation of the eye; and the same light may be quite different in intensity for two different observers. This relativity applies not only to intensity, but also to the other quantitative characters. The pitch (extensity) of a tone, and the size of a retinal or dermal impression are determined in part by the physiological condition of the receptors, and their anatomical peculiarities. Congestion of the inner ear may raise the pitch of notes, and the extensity of a colored area varies in different parts of the retina. Duration, and position in time and space, are similarly conditional.

Quality, on the other hand, is not relative. Relativity always implies more or less of; and there is no variation of more or less in respect to quality. When we speak of more or less of a certain quality, we really mean more or less in intensity, extensity or duration, of a sense datum of the specified quality.

For example: a reddish purple color is said to have more red, and less blue, than a bluish purple. This means simply that the red color is more intense in the first combination and the blue less intense (proportionately) in the first combination than in the second. One pure red cannot be either more red or less red than another pure red. The differences in color associated with a given stimulus, according to the adaptation of the eye, are due solely to differences in the proportionate intensities of the component primary colors.

The stimuli of the sense data, however, are conceived as absolute, in spite of the quantitative variations in the sense data themselves. Regardless of the brightness of the light as seen by dif-

ferent observers at a given moment, there is assumed to be only one value of the stimulus intensity. This peculiarity of relation of sense datum to stimulus has led to the unnecessary and confusing hypothesis that in every such case the observer is aware of an object ("sensation") which is his exclusive property: an absolutely distinct object for each observer. In reality, the situation is much simpler, and much more in accordance with the naive view of the man unsophisticated in philosophy. In such cases as those to which we refer, the different observers may really see the *same object;* but they see it with different quantitative characters, since these characters are determined by the perceiving organs as well as by the stimulus. Psychology does not drive us to abandon the belief in a *real perceptible* world, however much we may vary quantitatively in our perceptions of it, and in spite of the fact that some of us may be incapable of perceiving certain features of it at all.[58]

§2. Stimulus thresholds.

Sentienda must satisfy certain conditions in regard to their primary characters in order to be perceptible under given conditions of the organism. These conditions, conventionally called *stimulus thresholds,* are measurable, in terms of the stimuli. The term "threshold" is drawn from an old analogy of consciousness to a room, into which contents are supposed to enter: but the metaphor is mixed by the further convention of speaking of imperceptible and perceptible contents, not as "without" and "within" the threshold, but as "below" and "above" respectively. This mode of speaking arises from our common habit of schematizing increasing magnitudes on a line extending upwards from zero. In theory there are qualitative, intensive, extensive, and protensive stimulus thresholds. These we may refer to as the Q.S.T., I.S.T., E.S.T., and P.S.T. respectively. At present, not all of these are measurable for all senses.

The I.S.T. is the condition of *sufficient intensity* which a sentiendum must satisfy in order to be perceptible. A light, for ex-

[58]We cannot deny the *possibility* of there being qualities which no human being is capable of perceiving. There may be qualities corresponding to the infra red and ultra violet rays, for example. But we cannot affirm their existence. With the existence of purely hypothetical entities, neither science nor common sense has any concern.

ample, must have a certain minimal intensity in order that it may be perceived. Between zero and a certain maximal intensity (which we will call I_1), the light is imperceptible: above a certain minimal intensity (I_2) it is perceptible. The interval from I_1 to I_2 is the I.S.T. for light, under the given conditions of observation. The measure of the I.S.T. which is actually obtained in a series of measurements will, of course, depend upon the magnitude of the unit of measurements, and upon the criteria of perceptibility and imperceptibility adopted. But in any case, there will be an interval between I_1 and I_2, and this interval, which is the approximate I.S.T., will always include the actual I.S.T., if the measurements are reliable.

For convenience in certain practical applications of threshold measurements, the threshold is represented by a single number: and the number employed for this purpose is usually the mean of the two numbers which represent the approximate threshold, and is called the *threshold value.* Thus, if I_1 is 24, in the scale of measurements adopted; and I_2 is 29, the I.S.T. value is 26.5. This value represents the center of the zone within which the sentiendum is neither perceptible nor imperceptible: the center of the threshold.

The E.S.T. is the condition of *sufficient extensity,* and is, of course, in anatomical terms the stimulation of at least one receptor. This threshold is not determinable in terms of the stimulus, for the senses generally. On the skin, for example, a stimulus will excite at least one receptor, however small the stimulus may be areally, if it is sufficiently intense, and if there is actually a receptor termination at the point of application of the stimulus. In the case of audition, however, on account of the mechanical details of stimulation, the E.S.T. is determinable in terms of wave length of the stimulus, and is commonly called the upper pitch threshold.

The Q.S.T. is not strictly the condition of quality which a sentienda must satisfy; but is rather the condition under which a quality may exist: measured, like all thresholds, in terms of the stimulus. In the case of light, for example, wave lengths greater than a certain magnitude, have no color corresponding to them:

they are not stimuli of vision at all. Moreover, wave lengths less than a certain minimum have no color corresponding. There are then, for vision, two Q.S.T.'s, or "wave length thresholds:" and the corresponding two threshold values are the "limits of the visible spectrum." The lower pitch limit for tones, and the molecular weight limit for odors, are also Q.S.T's.

The P.S.T. can be determined only for specified intensities of stimulus. For light of a given intensity and area, for example, we may determine the minimal time of stimulation which causes perception, and the maximal time which does not. But for higher intensities the threshold value becomes lower, and any duration, however brief, will produce perception, if the intensity is sufficiently great.

§3. Physiological conditions of intensity and quality.

The intensity of any sentiendum depends, physiologically, upon the energy of *response* of the receptors, and consequent energy of the "nerve current" transmitted from them to the central nervous system (brain and spinal cord) for reflection outward to the effectors. The nature of the energy-variations in nerve cells are at present conjectural, but it is certain that these variations occur.[59]

The quality of a real sense datum cannot be conceived as dependent upon physiological processes at all, but the *perception* of all qualities does depend upon reaction, and the perception of any given quality depends upon the initiation of the reaction in a specific sort of receptor. Color, for example, cannot be perceived except through reaction initiated by retinal cone-cells.

From this dependence of perception upon receptors, it follows that whenever the appropriate receptor process is set up, the corresponding quality is perceived, *whether there is any sense datum "really" present or not.* Sense data perceived in this way are called "subjective" or hallucinatory. From this point of view,

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[59]If the "all or none" law is finally demonstrated for nerve cells, that is, if it is shown that any nerve cell can function ("discharge") at any given moment *with its fullest capacity only, i. e.*, a maximal discharge; then the variations in energy must be conceived as variations in the *number* of such discharges per unit of time (*e. g.*, per second.) Conclusions on this point must be held in abeyance for the present.

inadequate stimuli are the mathematical correspondents of hallucinatory sense data.[60]

Idio-retinal light, for example, and the "phosphenes" obtained by pressing on the eye ball, or moving the eyes sharply to the side (in darkness); and the "subjective noises" which occur in the ear (not the roaring of the blood stream, but the fine "clicks" and screeches which occur in pathological conditions), are sense data, with all the fundamental characters; (they are not "real," however, in the sense of being external to the organism). These and similar sense data are commonly called "subjective sensations," which perhaps may be considered properly as *organic.*

Hallucination, or experience due to inadequate stimulation of receptors, is a process which is intermediate between true perception and imagination, and the contents of hallucinatory perception are in their nature akin to sensory thought-contents, which are conventionally called "images." The analysis of thought-reaction, which is presented in a later chapter, throws further light upon the problem of hallucination.

The fact that there are hallucinatory sense data has been a source of perplexity to the philosophers for five hundred years, and had led to the hypothesis that *all sense data* are unreal in a strict sense, and are determined solely by physiological processes. This theory, known as epistemological dualism, was introduced by Malebranche, and holds that real objects have no quality, and that sensory qualities exist only when perceived, and then only "in the mind" of the perceiver. This view was constructed to meet the difficulty of "unreal sense data" above mentioned, and has been accepted partially by so-called "common sense," or popular philosophy, being held there in unresolved contradiction with the view that somehow perceived objects are really external objects. The term *sensation,* where used for *content,* rather than *awareness,* commonly implies this metaphysical theory of dualism. The very confusion between content and awareness involved in the term "sensation" is the result of the supposition, inherent in dualism,

[60]We say *hallucinatory* and not *imaginary,* for, as we shall show later, imagined sense data are in many cases "really" existent. *Imaginary* is not to be contrasted with *real* in psychology, but only with *perceived.* "*Real*" is here used in the popular significance in which we employ it when we say "I saw such-and-such an object, but there was no such object *really* there."

that the *existence* of the sense datum depends upon the *perception* of it.

The dualistic theory was apparently justified by the principle of parsimony, but as we pointed out earlier, this principle alone cannot settle the truth of hypotheses. The dualistic theory does not resolve satisfactorily the difficulties it was constructed to meet, and raises far graver ones. For the present, the more empirical view taken in this text is the most satisfactory one available.

§4. Temporal and spatial characters.

Duration and position in time are characters which are bound up so closely with relational factors that their analysis is exceedingly difficult, and little has been done with them. Much more attention has been paid to the spatial characters; extensity and position in space.

Extensity depends, physiologically, upon the number of receptors stimulated. This is obvious in the case of vision, audition, and the cutaneous senses; but it is not so obvious for the visceral sense, where the connections between receptors and central nervous system are of a peculiar sort. The chief difference in the latter case, however, is that the extensities of visceral data are in many cases relatively large in comparison with the stimuli. The apparent extent of a light or pressure area varies according to the particular part of the retina or skin affected. A flat disc applied to the skin of the palm of the hand is experienced as being larger than when applied to the arm. If the disc is pressed down heavily, the apparent extensity increases, on account of the larger skin area actually affected, and the additional protopathic and muscular feelings.

Area of stimulus affects intensity as well as extensity, because of the phenomenon known as *irradiation:* i. e., the tendency of the excitation of one area to affect adjacent areas, thus apparently lessening the stimulation of the original area. On the retina, an increase in the area stimulated increases the brightness perceptibly, if the intensity of the stimulus is kept constant and the areas stimulated are very small. Beyond the size of a few millimeters, at a meter's distance from the eye, the effect of further areal increase is negligible. This effect is due in part to dispersion of light in

the lens system of the eye, but is in part an actual irradiation effect.

Increasing the area of a small thermal stimulation of the skin may increase in two ways the intensity of the warmth or cold experienced: by lessening the irradiation, and by including more sensitive areas in the stimulated extent.[61]

The lessening of irradiation by stimulating larger areas is due to the fact that irradiation affects principally the edges of the stimulated area. The intensity of a sentiendum of small area is not increased by adding similar stimulation of other areas, noncontiguous to the first area, but may be lessened through contrast.

Retinal irradiation may be demonstrated by comparing the apparent sizes of a black disc or square on a white ground with a white disc or square of equal area on a black ground. The white figure will seem to be larger. A field of white discs closely and regularly spaced on a black ground, when placed at a proper distance from the eye, shows the irradiation effect in the hexagonal appearance of the discs. The striking effect obtained by holding the edge of a ruler between the eye and a strongly illuminated surface of diameter less than the length of the ruler is due only in part to irradiation, diffraction of the light rays by the edge being an important factor.

Spatial position as a character of sense data is called *local sign.* Light of the same local sign may have any one of an indefinitely large number of positions at different times in external space; and conversely, a visual datum of a given space-position may have any of the local signs at different times. The relation between local sign and the external position depends upon the relation of the external space position to the position of the eye in the socket, and to the position of the head. If, for example, the eye "follows" an object moving in space, either by rotation of the eye in the socket or rotation of the head, the local sign of the object may be maintained unchanged. The relation of dermal local signs to external space is equally complicated.

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[61] Barnhart & Bentley, Am. Jour. Psychol., Vol. 22, pp. 325-332.

In the auditory data, we have local sign, as well as extensity, in its "pure" state, unorganized into indications of external space. Although pitch is pure extensity, and pitches may be compared directly as such, the local sign of the receptors on which (at the variable end of the series) a note of given pitch ends, may assist in the identification of the pitch in perception, and in the discrimination of pitches so close together that as pure extensities they are indistinguishable. The difference between the trained or musical ear, and the untrained or unmusical ear, in regard to pitch discrimination and absolute pitch, can be explained on no other basis than the reliance on local sign by the individual with the first type of audition. This conclusion is in agreement with the fact that in vision, discrimination of local sign is far finer than discrimination of extensities, as is apparently also the case in touch. Whereas some "unusual" ears may be trained to a high degree of pitch discrimination, others remain "dull" even with maximal hearing. In these defective cases, it seems probable that through mechanical defects in the auditory apparatus, the tones do not terminate sharply at definite points in the series of hair-cells (receptors), but taper off diffusely.

§5. Movement.

Movement involves time and space, and it is through the combination of changes in local sign and in the temporal position character that we perceive the actual movements of objects in space. Since, however, movements of the sense organ, as of the head or eyes, or of the hand over an object, can produce the same combinations of positional character as the movement of an object with the sense organ at rest, it is evident that the muscular changes (in eye-muscles, neck-muscles, and arm-muscles) are the ultimate factors in the perception of movement. Movement, like space and time, is a complex affair, and its perception is also complex.

A moving stimulus, either on the retina or on the skin, produces an especially intense series of stimuli, and hence causes perceptual reactions of an especially definite and vigorous sort. This accounts for the fact that moving objects, tactual or visual, will be perceived under circumstances where fixed objects of the same

stimulus-intensity will not be perceived, either because of their low stimulus-intensity, the low efficiency of their receptors (as on the peripheral retina), or "distraction" from other sorts of stimulation.[62]

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[62]Auditory movement, where the transition from one pitch to another is continuous and not discrete—the *slurring* of notes—has important perceptual effects which merit investigation.

CHAPTER VI

SOME SIMPLE RELATIONS OF SENSE DATA

§1. Relations as objects of consciousness.

Relations can be perceived and thought about, just as sentienda may be perceived and thought about. The actual experienced world consists of sentienda related to each other in intricate ways, and it contains nothing else. This is true, at least, of the world exclusive of our experienced bodies: there are no experiencible things other than sentienda and relations, unless the *feelings* which are peculiar to our own organisms are to be classed as something other than sentienda. If there are objective realities in the outside world, besides sentienda and relations, these things are not experienced, and are not "given" in experience, and hence cannot be discussed rationally.

It is probably true that we can seldom, if ever, be conscious of sentienda without relations, or of relations without sentienda related by them. Yet it is possible to be conscious of two sentienda between which there is a specific relation, without being conscious of the relation between them: a relation of difference, for example, as in the case of two sounds differing in pitch. In some cases this failure is merely an accident of perception: a chance direction of attention away from the relation at the moment. Thus, two tones, differing considerably in pitch, may be heard, but the difference may not be observed, although it is of sufficient magnitude to be perceived readily at other times.

In other cases, relations may be imperceptible because the individual has not yet learned to perceive them. Thus, pitch differences which are imperceptible to the unpracticed ear, become readily perceptible after sufficient practice in pitch discrimination.[63] In still other cases, relations which actually exist between

[63] An individual who is at the first trial unable to distinguish between tones of 256 and 262 v. s., may, after some days' practice, succeed in distinguishing between 256 and 257 v. s.

perceptible sentienda never can be perceived in spite of maximal practice and all other possible favoring conditions. For example: if three tones are so chosen that the second is just perceptibly higher in pitch than the first, and the third is just perceptibly higher than the second, a tone may be inserted midway in pitch between the first and second, and another midway between the second and third. We now have a series of five tones, in which the difference between the first and second is imperceptible, and the difference between the second and third, third and fourth, fourth and fifth are likewise imperceptible. And yet these pitch differences actually exist, as is proved by the fact that the third is perceptibly different from the first and from the fifth, and the second is perceptibly different from the fourth.[64] Obviously, relations are objective facts whose reality does not depend on their being perceived.

The analysis of relations is a seriously neglected topic and our scientific knowledge of relations is fragmentary. We are not able, therefore, to classify them with either certainty or completeness, nor can we discriminate the simple or elementary relations from the complex. In neither of these directions has much progress been made, and our knowledge of relations remains in very much the same unsatisfactory condition as our knowledge of odors. At the most, we can but list certain relations which are of the first rank in scientific interest, and which perhaps are simple. Among these are: difference, resemblance, identity, magnitude, intermediacy (betweenness), concomitance, causality, inclusion, and certain time-relations and space-relations.

Time and space, as perceived, involve many relations in addition to the peculiar constituent ones. Magnitude and betweenness, for example, are both involved in time and space. A certain stretch of time or space may be greater or less than another. The second

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[64]If we represent the five pitches by p_1, p_2, p_3, p_4, p_5, we can show that p_2 must be different from p_1; otherwise it would be *perceptibly* different from p_3; and that p_2 must be different from p_3, otherwise it would be *perceptibly* different from p_1. And so also we can show that p_4 is really different from p_3 and p_5, although the differences are imperceptible. These facts apply to the sounds *themselves* ("sensations", in the confused terminology of the past), and are among the inescapable reasons why we must distinguish between sentienda ("sensations") and the awareness, or consciousness, of the sentienda.

moment of a time series, or the second position on a line, lies between the first and third. But magnitude and intermediacy are not peculiar to space and time: there are magnitudes and intermediacies which are not spatial or temporal.[65] On the other hand, there are certain relations which occur only in space or in time. The essential factor in time is the peculiar time-relation which we call *succession*. And this is one of the most important of all relations, for every concrete thing either succeeds or follows or is simultaneous with, everything else in the universe.

Simple relations, and relations which appear simple, are like simple sentienda in that they cannot be described. We can point out what we mean by one of the names, only by indicating a situation in which the relation is involved, and other situations in which it is not involved. The indescribability of any specific relation is a reason for tentatively supposing it to be simple rather than complex.

Because sentienda and relations are not practically isolable from each other, it is necessary to treat certain aspects of relation in connection with the characters of sentienda. But the characters of sentienda are to be distinguished from the relations which subsist around them. This distinction is especially important, and especially difficult, in the case of extensity and protensity. Extensity is essential for space relations, but it is not the space relation itself. Sentienda could not be in time if they had no protensity, yet protensity is not succession.

Relations exist primarily between sentienda; but relations themselves may be related in almost endless complications. Let us suppose two sounds, between which there is a certain difference in intensity, which we will call d_1, and another pair of sounds between which there is another intensity difference, d_2. Now d_1 and d_2 may be equal, that is to say, identical in so far as we consider the relations abstractly: or, they may differ, with a difference d', (a difference of the second order). We may suppose now two other pairs of sounds, with intensity differences d_3 and d_4,

[65]Intensity, for example, is magnitude. A patch of light may be more or less bright (intense) regardless of its spatial and temporal relations. And there are also intermediacies of intensity: one light may be between two others in brightness, regardless of the time and space relations of the lights. So there may be intermediacies of qualitative complexes: orange is between red and yellow in hue.

with a difference d″ between d_3 and d_4. Once more, d′ and d″ may have a difference of still higher order, and so on. Moreover, a pair of sounds may differ not only in intensity, d_1, but also in pitch, d_x: and there is a definite difference between d_1 and d_x.

The complications of relations are endless, but all relations rest ultimately in sentienda. Even the complex relations of mathematics and morals, which are treated abstractly, depend for their reality on ultimately related sense data.

§2. Identity and difference of sense data.

The identity and difference of sentienda with respect to their characters are especially important. The perception of difference in quality (differences in color, in odor, etc.); of intensity (loudness, brightness, etc.): of extensity: of duration and of position are involved in almost all the practical reactions of life. Difference may be perceived with great clearness, if the differences are sufficiently great; but identity can never be distinguished from differences which are imperceptible. Thus, if two lights differ largely in intensity, the difference may be unmistakable: but if no difference is perceptible, one cannot be sure, from immediate observation, that the two are actually identical, rather than differing by an imperceptible amount. As we have seen in the preceding section, it is possible to show that certain data which are apparently identical in one of their characters, are really not identical.

The measurement and comparison of differences is an important part of experimental procedure in psychology. Such measurements deal with immediate differences in respect to sensory character, and with identities and differences of differences, but not with differences higher than the second order.

§3. Threshold differences of sense data.

Since differences may be so small as to be imperceptible, it is obvious that there must be *difference thresholds,* just as there are stimulus thresholds. If we compare, for example, a tone of standard pitch, P, with a series of tones, p_1, p_2, p_3, etc., varying by small gradations above and below P, we shall establish four important values of p. These are: p_A, the least value of p which is perceptibly greater than P; p_a, the greatest value of p which is *not* perceptibly greater than P; p_B, the greatest value of p which is per-

ceptibly less than P; and p_b, the least value of p which is not perceptibly less than P.[66] Two threshold values are thus determined: one, $P\alpha$, by a point intermediate between p_A and p_a; the other $P\beta$, by a point intermediate between p_B and p_b, each threshold point being the mean of two differences between P and p, and representing a difference which is *neither perceptible nor imperceptible.* These two threshold values are not necessarily equal.

The difference threshold (D.T.) is properly represented, not by the absolute difference between P and p, but by the ratio of this difference to P, which may be expressed as a ratio or percentage. For example: if P is 100 vibrations per second, and the four vibrations rates of p are 96, 98, 101, and 103, the threshold points in the scale of measurement are 97 and 102. The thresholds are not properly expressed as 3 and 2 (100-97 and 102-100); but as 3/100 and 2/100. This method of expression is important for the understanding of Weber's Law.

§4. The intensity difference threshold and Weber's law.

A significant constancy of the intensity difference threshold has been observed, and is generally designated as *Weber's law.* Unfortunately, the physiological texts, and some psychological texts, confuse this principle with a mathematical interpretation thereof, properly called *Fechner's law,* or *Fechner's formula.*[67] It is important that the student should distinguish clearly between these two.

Weber's law can be stated briefly as follows: *The intensity difference threshold expressed as a ratio (or percentage), is approximately constant for changes in intensity of stimulation alone, throughout a certain limited range of intensities.*

For example: if the threshold difference for a gray of 100 units brightness is 1 unit, the threshold difference for a gray of 500 units brightness will be 5 units: the threshold ratio in each case being 1:100. And this same threshold will hold for values

[66]The values p_A and p_B are sometimes taken as threshold values, instead of $P\alpha$ and $P\beta$. But p_A-P and P $p\beta$ are *just perceptible differences* (j. p. d.): commonly termed *just noticeable differences* (j. n. d.), and obviously are slightly greater than the true threshold-differences.

[67]Weber's law was discovered and formulated by G. T. Fechner from a study of tactual intensity difference thresholds obtained and reported by E. H. Weber, and given Weber's name by the discoverer.

of the stimuli intermediate between 100 and 500, and for a certain extent of the range above and below these values.

The limitations of Weber's law are important. In the first place, it applies to intensity differences only: this fact needs especial emphasis, since assumptions that it should apply to other characters have spoiled many discussions of sensory psychology. In the investigations of quality and extensity differences, no principle analogous to Weber's law is found.[68] In both of these fields, the difference thresholds are more nearly constant when expressed, not as ratios, but as absolute differences. For example: in the case of the pitch-difference threshold, for wide variations of P, the threshold difference P-p is approximately constant, the ratio of this threshold difference to P, therefore, not being constant. In the case of tactual and visual extensities, the difference threshold varies with the spatial and temporal details of comparison, but follows the rule for pitch difference if the areas compared are superposed on the same sense area, either simultaneously or in immediate succession. Qualitative difference thresholds, and thresholds of duration difference, follow no such simple laws.

The second important limitation acknowledged by Weber's law is that of range. In any case, constancy of the threshold holds for a certain range of stimulation intensities, and fails both above and below this, the threshold usually becoming greater for both the too high and the too low intensities.

In the third place, the law holds for the same sort of stimulation only. The threshold value for one sense is not the same as for another: and within the same sense, the thresholds may differ for different stimuli. Thus, the difference threshold determined for a certain range of red light intensities cannot be expected to hold for any range of blue light intensities.

Finally, the physiological and psychological condition of the individual must be approximately constant. Thresholds determined for one person will not, in general, hold for another; and thresholds determined in states of fatigue, or inattention, or dis-

[68]Certain observations do seem to show, however, that the D. T. for the size of detail in pattern-vision follows a law analogous to Weber's, if the absolute size of the stimulus details is well above the stimulus threshold. See Johnson, H. M., in the *Journal of Animal Behavior*, 1916, Vol. VI, pp. 169-221.

ease, will not necessarily agree with those determined for the same subject in vigorous health, and with proper attention.

Fechner's formula was developed from Weber's law by making the following assumption: that threshold differences in intensity of sense data, under the conditions for which Weber's law holds, are all arithmetically equal. For instance, it is assumed that the difference in brightness between the light of 100 units brightness and the light of 101 units is exactly the same in magnitude as the difference between the light of 500 and the light of 505, if these are threshold differences. Yet the measures of these differences are not arithmetically equal, but are geometrically equal; that is, they are equal ratios.

By a simple mathematical operation, this assumption leads to a formula in which the relation of any actual intensity of a sense datum to the measured intensity of the stimulus is given. The formula is:

$$S = C \log R$$

where S is the intensity of the sense datum ("sensation"), and R is the intensity of the stimulus, ("Reiz") K and C being constants which are valid for the particular mode and conditions of measurement.

The assumption upon which Fechner's formula is based is objectionable for many reasons. In the first place, it is quite arbitrary, and has no foundation except its necessity for the development of the formula. In the second place, it is contradicted apparently by the actual facts in the case of light intensities, since Weber's law holds for light intensities when measured by the visual comparison procedure; in which case that which is compared are not the true physical stimuli, but the perceptible brightnesses themselves.[69] In other words, it is clear that in the case of light intensities, the absolute value of the threshold difference *does* increase as the standard brightness increases.

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[69]The scales of measurements in which light intensities are measured are psychological rather than physical, since they are derived by direct observation of brightnesses, the measurements depending upon threshold determinations. The "stimulus" measurements of light, in fact are standardized with reference to intensity difference threshold measurements. That Weber's law should hold for light intensities is, therefore, a striking refutation of Fechner's fundamental assumption.

Finally, experimental work on an *intensity* deduction from Fechner's formula throws additional doubt upon it. If the assumption upon which the formula is based were valid, then (as can be shown mathematically), where two clearly perceptible differences in intensity of a certain sense datum are perceived as equal, the stimulus differences should be in equal *ratio*. For example: the difference between intensities 100 and 150 should appear equal to that between 150 and 225. In experimental tests, this expectation is sometimes realized, but sometimes it is not. In some cases, for example, where observers are required to divide the difference between two intensities by adjusting a third intensity to be midway between the two, the geometric mean is frequently chosen, but often the arithmetic is chosen. There is no escaping the conclusion that "equality" means sometimes equality of absolute measure, and at other times, or to other persons, relative equality.

Weber's law is of theoretical interest, but its practical aspects are perhaps discouraging. Intensity difference thresholds actually vary enormously in all senses, in accordance with the method of presentation and comparison of the intensities. This, of course, does not invalidate Weber's law, since it specifically applies only to conditions where the methods are uniform. But it has prevented the determination of any standard, either of range or of threshold constants for the various senses.

In the case of pressure applied to the skin, if two intensities are applied to the same area, briefly, and in rapid succession, the D. T. may be as low as 1:100, with 50 to 100 grams standard. But if applied for longer periods, or with several seconds between the intensities, or if the two are applied on different skin areas, the ratio may run to 1:5 or even more. It seems probable that in all the senses, under optimal conditions of stimulation, the D. T. ratio for a certain range of intensities may be as low as 1:100, or even lower, for normal healthy individuals, with sufficient practice in difference discrimination. With defective sense organs, feeblemindedness, ill health, or non-optimal conditions of test, the ratio increases.

§5. Intermediacy or betweenness.

Intermediacy is one of the most important of the relations of sense data for our analysis of these data, and it is through use of this relation that we are able to schematize the elementary data as we have done in the preceding chapters. A sense datum may be intermediate between others in many different ways; but intermediacies in respect to the characters earlier listed are most important for our purposes. These intermediacies, except for space and quality, are all *linear,* and susceptible of gradations. Intensities, for example, may be schematized as a line; and since for a pure linear series there is no question of direction in any other dimensions, they may be schematized as straight lines. Intensities constitute a potentially continuous gradation, since there is a possible intermediate degree between any two intensities, whether perceptible as intermediate or not. This continuous gradation is simple in the case of all quantitative relational senses, but with respect to qualitative gradations there is the following peculiar situation which we have already noted.

In any quantitative series, there are two extremes, and any other member of the series is intermediate between the two. In qualitative series, such as those of taste and vision, there are no extremes, and certain terms in the series are non-intermediate to certain other terms, although they are intermediate to still others. In the color series, for example, R is not intermediate in quality to C and B. There is no respect except the purely spatial one of the spectrum in which any of these three is *between* the other two. Yet there is a gradation of intermediacy of many hues between pairs of these—such as the purples, between R and B; the orange reds, oranges and yellows, between R and C; and the greens and blue-greens between C and B. This peculiarity of the color series is responsible for our concluding that the series is based upon three fundamentals in the color series, and is intelligible as soon as we conceive of them as fixed elementary colors, and the gradations between them as mixtures.

The existence of critical points in a qualitative series is of the highest importance for sensory analysis. Through this we were enabled to decide that the pitch series is non-qualitative; and it

furnishes an additional support for the "three-color theory" of vision, since four mutually non-intermediate colors cannot be found. Furthermore, it is through the use of critical points that we can eventually determine the exact primary colors. The R or the B may not be in the spectrum at all: this point has been admitted by almost all theorists. The primary red may be a hue more purplish than the extreme red of the spectrum: or the B may be actually more violet than the extreme short wave end of the visible spectrum. But the C color must be in the spectrum, and its determination is the determination of a critical point within the spectrum; a determination which is quite possible, although as yet it has been made but roughly.

CHAPTER VII

SOME SENSORY MEASUREMENTS

§1. Measurements and tests.

It is neither feasible nor desirable to introduce here a detailed account of the methods and instruments required for accurate measurement of sensory capacity. Such an account must necessarily be both technical and voluminous, and is given properly in a laboratory course: the technique of accurate measurement can be acquired only by a laborious process under competent supervision. There are many pitfalls for the unwary, and an extensive range of cautions must be observed; so that it is impossible for the untrained worker to obtain reliable results, except for clinical purposes where comparatively rough measurements will suffice. It is possible, for example, to diagnose a grave defect of vision or of audition by the rough methods commonly employed in medical practice; but the lesser defects, even some of those which may have serious practical consequences, and the differences in sensitivity of "normal" individuals, can be measured only by the refined methods of the psychological laboratory.

The methods and technique of accurate measurement include not only a precise instrumental technique, and exact methods of presenting stimuli with proper gradations and order, but include also the proper time arrangement; the use of carefully planned warning signals; and various detailed provisions to secure uniformity of attention, lack of bias, and absence of emotional disturbance on the part of the reactor.

In certain cases, it is important and possible to make determinations in which small units of measurement are not demanded, and in which the reactor is not required to determine just perceptible and just imperceptible values. Such determinations are called *tests;* and although in each case certain details of technique

are indispensable, this technique is neither as detailed nor as difficult of acquisition as the technique of exact measurement.[70]

The measurements described below are applicable directly to the Stimulus Threshold (ST),[71] the Difference Threshold (DT), and the Range of Sensitivity (RS), but are capable of extension to cover a much wider range of functions, such as the adaptation process.

§2. Olfactory and gustatory measurements.

The most obvious method of measuring olfactory and gustatory sensitivity is by means of odorous substances dissolved in dry air; and sapid substances dissolved in distilled water. The IST for taste and the IST for smell are stated commonly in terms of the relative parts of the specific substance .to parts of air or water by weight, which make the substance *just perceptible.* This measurement is not accurately the IST, which is a trifle below the "just perceptible" point: the exact IST is not deducible from measurements in which the just perceptible quantity (JPQ) alone is given.

Theoretically, it should be possible to measure the IST (or the JPQ) by the method described. Actually, the difficulties are great, and for olfaction they are almost insuperable.

In measuring gustatory sensitivity, one may prepare, for a given substance for which the IST is desired *(e. g.,* cane sugar), a series of solutions of graded concentration, and proceed by presenting these to the reactor for determination. The series of concentrations must be prepared with reference to the degree of accuracy required in the measurements: that is, the steps between successive degrees of concentration employed must be as small as the specified limit of measurement. If it is required that the IST for sugar shall be determined to the nearest unit *per cent,* the concentration must increase (and decrease) by units *per cent.* The series of solutions employed, in that case, will be concentra-

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[70]The brief account of measurements and instruments included here is intended merely as a set of prepared notes, to which the student may refer and relate the demonstrations and further details which may be given by the instructor.

[71]The ST is sometimes designated the RL, from the German "Reiz" (stimulus) and the Latin "Limen" (threshold). The DT is sometimes designated the DL. Such usage is needlessly ponderous.

tions of 1%, 2%, 3%, and so on, or of 1%, 2%, 4%, 8%, and so on, the geometric series being more suitable than the arithmetic for some purposes. If, however, a finer measurement is required, the successive concentrations in the series must differ by smaller amounts.[72]

The temperature of the solution must be kept constant, and the quantity of solution applied, as well as length of time during which it is applied, also must be kept constant. Conditions of attention and fatigue must be standardized by elaborate precautions in procedure.

The solution may be applied in quantities sufficient to bathe the entire tongue (*i. e.*, a measured "mouthful" may be taken). In this case, the mouth must be washed out each time, with a measured quantity of distilled water, during a measured length of time, with standardized position or movement of the tongue and mouth. These precautions are required, not only to remove any sapid substances already in the mouth, including saliva and remnants of preceding stimulus solution, but also to minimize the effects of saliva in diluting the stimulus solution.[73]

The secretion of saliva is so irregular that the "mouthful" method is less satisfactory than the "local" method, which moreover must be employed where it is desired to test local distribution of sensitivity. In the local method, a portion of the tongue is cleansed with distilled water, dried by a non-sapid absorbent, and then the solution "painted" upon the area under investigation—perhaps a single papilla—by means of a camel's hair brush. By this procedure, dilution effects are minimized, and exact localization of sensory areas is determined. The results, however, are not indicative of the sensitivity obtaining under normal conditions, which are more nearly represented by the "mouthful" method.

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[72]The conditions laid down here apply to sensory measurements in general. Various attempts have been made to calculate the ST and DT in units smaller than the units of measurement, as if one should use a series of solutions differing by steps of 5%, and from the result attempt to calculate the ST to the nearest unit per cent. Such calculations are of no practical value.

[73]It is assumed that the mouth and teeth have first been thoroughly cleaned mechanically.

Olfactory measurements present still greater difficulty. Apparatus for the introduction into the nostrils of measured quantities of dry air, at determinate temperature, and containing determinate percentage of gaseous substance, has been ideally planned; but no such apparatus has been made practically available. The difficulty of maintaining a specified concentration of the odorous substance, avoiding precipitation on the sides of containers, etc., is so great that fixed gases only could be employed with accuracy; and even so, the apparatus would be so complicated that it would be applicable only to highly specialized research.

As a substitute method, solutions of odorous substances in non-odorous media have been employed. Various concentrations of butyric acid in water, for example, may be employed in this way, the reactor being allowed to "sniff" at broad mouthed bottles, which contain standard quantities of the solution at standard temperature. This *solution method* is admittedly rough, but it is the best practically available. The odorous substances soluble in water are limited in number, but it is possible that non-odorous solvents for oils and resins may be found.

The needs and difficulties of olfactory measurement have led to the construction of an "olfactometer" by Zwaardemaker, which is ingenious but not practically satisfactory. In Zwaardemaker's olfactometer, a glass tube has one end curved for insertion in the reactor's nostril; over the straight outer portion of the tube is fitted a porous porcelain cylinder, which is to be soaked in a solution of an odorous substance. As this cylinder is drawn outward, a greater length of its inner surface is exposed to the current of air drawn through the tube as the reactor inhales. The solution impregnating the porcelain cylinder is assumed to be of a standard concentration, and at a standard temperature; the air inhaled must be of a standard temperature and humidity, and the inhalations must be as nearly as possible of standard length and energy; and preceded by standardized ventilation of the nasal cavities with dry air. This method meets so many points of difficulty that it is practically no better than the simple solution method, and the instrument has been useful principally as a laboratory instrument for the development of technique.

§3. Visual measurements.

Measurements of visual capacity, aside from the function of the extrinsic muscles of the eye, which control convergence and shifting of the direction of vision, may be classed under two heads: measurements of *sensitivity*, and measurements of *acuity*. Acuity is in general the ability to distinguish space-forms, where these are of small magnitude; and specifically, the power to distinguish lines and points. Acuity depends both upon what physicists call the "resolving power" of the lens system of the eye, and also upon the perfection of function of the retina. Assuming that the lens system of the eye is "normal," or so corrected by external lenses as to give the sharpest possible retinal image, further variations in acuity depend upon irradiation and the difference-sensitivity for brightness of the part of the retina stimulated. If, for example, the images of two bright lines, separated by a dark strip, fall upon the retina, the stimulated areas will not be sharply defined, physiologically, but will spread by irradiation into the dark strip. The lines will be seen as *two,* therefore, when the geometrical images of the bright lines are separated sufficiently, so that the center of the strip between them is perceptibly darker than the central portions of the two bright lines.

The optical properties of the lens system of the eye may be measured by the methods of physiological optics, and defects in the lens system approximately corrected. The typical defects clinically recognized and corrected are: (1) *hyperopia,* or hypermetropia, (2) *myopia,* and (3) *regular astigmatism.* In the first of these, the refractive power of the lens system is too small for the length of the eye:[74] in the second, the refractive power is too great for the eye length; and in the third, the refractive power

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[74]The abnormality usually consists in an unusual length of the eyeball, and not in a lens of unusual refractive powers. In the hyperopic (hypermetropic) eye, for example, the lens is usually normal, but the eye is so short that a lens of increased refractive power is required.

An ocular defect of a different sort, namely *presbyopia,* or old-sightedness, due to hardening of the crystalline lens, and consequent loss of power to accommodate the eye for near vision, is also corrected by convex lenses. But whereas true hypermetropia can be corrected for *all* distances by a single lens, so that the hypermetropic eye, with proper lens, becomes virtually a normal eye; presbyopia can be corrected by one lens for a certain range of distance only. Hence, the presbyopic eye may be normal for "far vision" without spectacles: requiring "reading glasses" for short range, and sometimes glasses of slightly less curvature for "middle range."

is greater in one meridian than in the meridian at right angles to that. Corrections are made therefore for the three cases by spectacles with (1) convex lenses, (2) concave lenses, and (3) lenses of cylindrical curvature. Since these defects result in lowered acuity of vision (although they may not be the sole cause), the usual oculist's practice is to determine by a trial-and-error method the sort of lens which will approximately correct the defect and produce the maximal acuity for the eye tested. This method, since it relies upon the critical observation of the reactor himself, involves in high degree the usual difficulties of psychological measurements, and is successful only in the hands of the expert who understands the psychological difficulties, except where merely rough correction of a gross defect is desired. This results in the large percentage of misfits in oculists' prescriptions. This method, of course, cannot be used successfully on children, and the more careful oculists substitute other, and objective methods in examining children's eyes.

The determination of retinal acuity, when defects in the lens-system are assumed to have been corrected, or the determination of total acuity, when the lenticular and retinal factors are not discriminated, is also a psychological matter. For exact measurement, the *minimum visibile*[75] *is determined.* The minimum visibile is the smallest separation, measured in angle of vision, between two lines, or two points, which can be discriminated as two, instead of fusing into one. Whereas it might be supposed that the minimum visibile is a matter of retinal local sign; *i. e.*, dependent upon the smallest perceptible difference in local sign; this is not the case. The minimum visibile is fundamentally a matter of difference-sensitivity for brightness, two points being distinguishable as two when the area between the images of the two in the retina is distinguishably brighter or darker than the two images.

The minimum visibile may be measured by presenting two black lines drawn close together on a white surface, and finding the distance of the surface from the eye, at which the two lines are just distinct, and the distance at which they fuse into a single line. The measurements can be transferred into visual angles, from the

[75]Pronounced viz-i-beel, with accent on last syllable.

known distance between the lines, and the distances of the lines from the eye. In using this method, however, the lines should always be six meters or more from the eye, since nearer positions introduce differences in accommodation of the eye for the different distances. Theoretically, the lines could be fixed in distance from the eye, and the distance between them varied. On account of the difficulty in making the small adjustments necessary, this method is not easily employed. A single line, which is doubled by use of an Iceland spar prism; or a device such as the Ives visual acuity instrument, which produces a field of lines of variable width and separation by means of a special optical system, may be used.

The most reliable measurements with sharp white lines varied in angular separation on a black ground, gives a measure of acuity for "normal" eyes under 1′ visual angle of separation of the lines. With optimal conditions of illumination and observation, this measure may be brought to 30″, and to 15″ for unusually acute eyes; but 1′ is considered as "normal," or satisfactory acuity, indicating that both retinal conditions and the refraction of the lens system of the eye are sufficiently good for practical vision.

For rough tests of the refraction of the eye, assuming that the retinal conditions are approximately "normal," *Snellen's Letters* are used. These are specially designed, square-formed capital letters, arranged in horizontal rows, each row containing letters of a single height. It is assumed that a letter of 5′ angular height, the thickness of the lines of the letter being 1′, should be "read" correctly by the normal eye. The rows of letters are so made that the letters of one row will subtend the standard 5′ angle at a distance of 3 meters from the eye: the letters of the next row subtend the 5′ angle at a distance of 4 meters, the next at 6 meters, and so on, up to 60 meters. A working distance of 6 meters is usually adopted as a standard, and the acuity is designated in terms of the ratio of the actual reading distance, to the distance from which the smallest letters which can be read will subtend an angular height of 5′ at the eye. For example: if a patient, at 6 meters distance, can just read the row of letters which subtend an angle of 5′ at 15 meters by the normal eye, his visual acuity

is said to be 6/15 or 2/5 of normal. It is necessary in some cases to paralyze temporarily the muscle of accommodation (ciliary muscle) by means of atropin, or an atropin derivative, in order to measure the acuity in the "resting" condition of the ciliary muscle, and this procedure is commonly employed by oculists. Optometrists, on the other hand, proceed without atropin. The psychological factors of the test are so important that better results are frequently obtained by careful technique, without atropin, than by careless technique with atropin. Nevertheless, certain errors, notably hyperopia, are so concealed by spasm of the ciliary muscle that their extent is not disclosed without the use of atropin or some other cycloplegic.[76]

A simple visual acuity instrument devised by P. W. Cobb presents two white rectangles on a black ground. The white rectangles are always equal in width to the black strip separating them, whereas the width of the rectangles can be varied from zero to a sufficient maximum by continuous gradations. In one laboratory form of the instrument, the maximal width of each of the white rectangles is 5 millimeters, and the length is constantly maintained at three times the width; so that the total figure presented is always a square. The axis of the figure can be rotated through 180°, so that the possibility of guessing is minimized. For general experimental and test purposes, this instrument has many advantages.

Sensitivity of vision is measured in terms of the light falling upon a given area of the retina. The unit of luminous intensity is that of the flame of a supposed standard candle,[77] and a surface is rated in a rather indirect way by its relation to this standard. The unit of brightness, the "candle per square centimeter" is the brightness of a surface such that a square centimeter of the surface has exactly the illuminating power of a standard candle.

The unit of *illumination* must not be confused with the unit of brightness. The illumination-unit is the *meter-candle;* that is:

[76]A cycloplegic is a drug which paralyzes the ciliary muscle and so prevents accommodation. A mydriatic dilates the pupil, either by causing strong contraction of the radial muscular fibers of the pupil, or by paralyzing the circular fibers.

[77]Actually, the standard of luminous intensity is a certain electric lamp, kept by the Bureau of Standards at Washington. This lamp has a certain candle-power (luminous intensity) when operated under specified electrical conditions.

the density of light thrown by a standard candle on a surface at a distance of one meter from the candle. The *brightness* which such a surface will have depends upon how much of the light thus falling upon it is absorbed, and how much reflected; and also upon the character of the surface, whether it is specular (like glass or a polished metal), or matt (like paper or chalk). In general, any surface will present different brightnesses from different points of view. In any case, all measures, both of brightness and illumination, are ultimately made by the purely psychological equation of brightnesses. The measurement of light by such methods is called *photometry.*[78]

The sensitivity of the eye varies with adaptation, and is so great in darkness adaptation that the technique of measurement for the normal eye is very difficult. Rough tests of adaptation and of the sensitivity of different regions of the retina are easily made in a dark room by illuminating a small surface, such as a square of milk glass, set in the front of an illuminated box. If the light transmitted through the glass be decreased by diaphragms and diffusing screens, a point in brightness may be found such that the light is invisible to one coming into the dark room from daylight, but will appear after several minutes. The brightness may be made so low that fifteen or twenty minutes adaptation is required to make the light visible. At a certain brightness the light may be visible to the paracentral retina, so that it is seen by looking slightly to one side; and yet be invisible to the fovea, and hence it will disappear when the gaze is centered upon it. Adaptation is not as great in the fovea as in the other portions of the retina, but even in the fovea some adaptation occurs.

The difference threshold for brightness is measured by several means. The most direct method consists in obtaining the brightness on contiguous parts of the same surface, so as to obtain the just perceptible and just imperceptible differences. This is the *method of direct comparison,* a less exact and more rapid form of which is the method chiefly used in photometry.

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[78]For discussion of units of light measurements, see Cobb, Photometric Considerations Pertaining to Visual Stimuli. *Psychological Review,* Vol. 23, pp. 71-88.

The difference sensitivity on a small central area of the retina has been shown to depend upon the brightness of the surrounding field, being greatest when the surrounding field is approximately equal in brightness to the brightness for which the threshold is being measured.[79] With decreased brightness in the surrounding field, the difference sensitivity for a small central area falls off slightly: with increase in the surrounding brightness, over that of the central area on which measurements are made, the sensitivity falls off very rapidly. For the optimal condition, the threshold is about .3 of one per cent, where the standard brightness is 17 candles per square meters. For the same brightness of surrounding area, with changes in the brightnesses compared in the small central area, the threshold rises to one per cent at 1/10 the brightness of the surroundings, and .4 of one per cent at the brightness of 10 times the surroundings. Obviously, Weber's Law does not hold for brightness differences, unless the surrounding area and the area of discrimination are approximately of equal brightness.

In another method (flicker photometry) the two brightnesses are obtained alternately on the same area, at rates of alternation so slow that flicker is obtained if the brightnesses are sufficiently unequal. After having determined the upper and lower thresholds for brightness difference, by either the method of direct comparison or flicker photometry, the point of brightness equality between the two lights used may be assumed to be the point midway between them. As a matter of fact, in photometry, this point is estimated by adjustment. In both flicker photometry and direct comparison photometry, the most accurate work is done by means of beams of light falling upon "white" diffusing surfaces, with or without lens systems introduced between surface and source, or surface and eye. The physical intensity of one or both beams employed may be reduced by several methods: (1) By increasing the distance between the source and the surface. The brightness of the surface varies inversely as the square of the distance from the source, if a point source be used; and with a very small source, such as a short length of incandescent filament, the assumption

[79] P. W. Cobb, *Journal of Experimental Psychology,* Vol. I, 1916, pp. 540-566.

that it is a point gives results which are approximately accurate. (2) An absorbing screen, such as "smoked" glass, of known absorption power, may be inserted between source and surface, or between surface and eye. Such smoked glass, if white light is employed, must be "non-selective," *i. e.,* it must absorb all visible rays in equal proportion. In the case of colored light, including several wave lengths, the screen must have equal absorbing ratios for all wave lengths employed. (3) The beam may be interrupted by an *episkotister:* a rotating disc with "open" (cut-out) and "closed" sectors of adjustable angular width. If such a disc is rotated at a speed higher than the critical frequency, the reduction in the energy of the beam, and consequently of the brightness of the surface, is proportionate to the ratio of closed sectors to the total disc. This is in accordance with the Talbot-Plateau Law, which may be stated as follows: If a surface is illuminated by an intermittent beam of light, the rate of intermittence being above the critical frequency for the beam, the brightness of the surface will vary directly as the duration of illumination divided by the total time. For example: if the open sectors in the disc total 120°, and the closed sectors therefore total 240°, the reduction in brightness, provided the rate of interruption is greater than the critical frequency, is 2/3; and the brightness is 1/3 the brightness obtained when the disc is entirely removed. (4) Each of the surfaces may be illuminated by another surface of uniform brightness, which then becomes the primary source. By varying the area of this primary source, by means of a diaphragm covering it, the brightness of the second surface may be varied, the brightness varying directly as the area of the primary source exposed.

The most useful type of photometer for direct comparison is the Lümmer-Brodhun photometer, in which two surfaces of plaster or magnesia are illuminated independently from two sources, and by an ingenious arrangement of lenses and prisms, a part of one surface is seen contiguously to a part of the other surface.

Flicker photometry, in which the two beams of light are made to fall alternately on the same surface, is employed chiefly where it is necessary to compare the brightnesses of lights of different colors: a difficult procedure in direct comparison.

A simpler but less accurate method of direct comparison of brightnesses employs Maxwell's discs of a standard "gray" and of dead black. Under constant illumination, the brightness of such a combination, rotated at a speed above critical frequency, will vary directly as the angular width of the "gray." By means of two pairs of discs, one small pair superimposed upon a large pair on the same rotating spindle, two surfaces of different brightnesses may be made contiguous, and the difference threshold may then be measured directly.

Two differences in brightness, well above the threshold, may be compared by using either three or four surfaces. The brightness difference between surface 1 and surface 2 may be compared with the brightness difference between surface 2 and surface 3: or the difference between the brightness of surfaces 1 and 2 may be compared with the difference between surface 3 and 4. The brightnesses may be varied by using Maxwell's discs under uniform illumination, or each surface may be illuminated independently, and the brightness of each controlled in any of the four ways above described.

Measurements of color sensitivity may be made accurately by the use of spectral light, either by direct vision in the spectroscope, or by projection of spectral light on a diffusing surface, such as a plaster of Paris or magnesia surface. The IST and IDT for the various colors may be determined, and the range limits also determined. In work on color blindness, determination of the limit of the red end of the spectrum is important. All such work requires a purified spectrum, obtained by passing the light through two spectrometer systems in succession, and requires a high degree of skill.

Difference Thresholds for Hue and Saturation

The difference threshold for color has been measured in a very simple way by means of an ordinary spectromometer. A narrow slit used in the eye-piece permits the viewing of a narrow band in the spectrum. The telescope is set to bring into view any desired spectral band, and then the telescope is carefully moved in either direction until the band just perceptibly different from the

original band has been passed. A better method is to illuminate a white surface by the two spectral colors to be compared, the two colors being contiguous, and presented simultaneously. Varying results have been obtained, but it seems clear that the difference sensitivity is higher at certain points in the spectrum than at others. Maximal difference sensitivity, less than 1 $\mu\mu$, is found at 580 (orange-yellow) and 490 (green-blue), and minimal difference sensitivity in the red (4.7 at 650 $\mu\mu$ and longer) yellow-green, (1.88 at 530 $\mu\mu$), and pure blue, (2.15 at 450 $\mu\mu$), ranging upwards to 4 $\mu\mu$. (Uthoff's measurements).

This determination of difference sensitivity for colors is exact when the compared bands are equated in saturation and brightness by mixing white light with one or the other, and reducing the intensity of one by a rotating disc, smoke glass wedge, or other device.

The difference threshold for saturation might be worked out with relatively little difficulty by the systematic adding of different proportions of white light to a color selected as a standard. For accurate measurements, a band of spectral color should be employed. Measurements have been made, however, by means of Maxwell's discs, employing a colored paper and a gray paper of equal brightness. Under such conditions, the saturation threshold measured in degrees of gray added to the color may be as low as 1 per cent for certain colors and brightnesses. For a certain red at a single brightness, Geissler[80] found that the saturation DT was lower for low saturation than for high.

Tests of Color Vision

Certain practical work on color blindness requires measurements which shall have a high degree of certainty rather than fineness of measure. Such measurements as previously stated we call *tests*. Many tests for the detection of totally and partially color blind and color weak persons have been devised, but the perfect test is yet to be sought. Color tests in general fall into four classes: (1) Naming-tests, (2) Matching-tests, (3) Pattern-tests,

[80] *American Journal of Psychology,* Vol. 24, 1916, p. 171ff.

and (4) The Nela test. All of these depend upon the discrimination of color differences which are large for the normal eye.

1. In naming-tests, such as Nagel's, the reactor is required to select from a number of tinted cards, skeins or samples of colored worsted or silk, or from a number of colored balls, those having approximately the colors indicated to him by name. Thus, he may be asked to pick out the greens, the reds, and so on. Or, he may be required to name all of a series of colors presented to him. This method has little value for the detection of color blindness, since the sensitivity to colors is not indicated by the associations of words with colors which the reactor may have formed. In many cases, individuals whose color-vision is normal, fail to name colors correctly; and in some cases, typically color blind persons may name correctly the colors they see imperfectly.

The naming method is, however, of practical importance, since the recognition of color is essential in many fields of work. The railroad engineer, for example, must not only *see* red and green normally, but must recognize each quickly. That is to say, he must have a dependable association of action with each of the two colors, and the nature of his verbal association with the colors is the index of his practical associations. In short, if the engineer could name red and green correctly under all conditions of railroad vision, it would not matter how much their appearance to him differs from their appearance to other people. But color blindness is always a grave hindrance to color discrimination, and hence it is essential that color vision itself shall be tested, as well as color naming.

2. Matching-tests were first introduced by Holmgren, and the Holmgren test, Wilson test, Jennings test, and many others are constructed on the same principles. In such a test, a group of colors, and a sample color, are presented to the reactor, and he is required to select from the group all those which match the sample in hue. Worsteds are used generally for the colors, on account of the relative permanence of the dyes, the large range of hues obtainable, and the absence of sheen. These tests, when the proper colors are used, and when given by experts to reactors who perfectly understand the problem, are quite satisfactory for the purposes intended. In the hands of inexpert testers, they are

highly unreliable, and very confusing results are obtained from children and from adults who are unfamiliar with the handling of colors. Confusion between color differences on the one hand, and brightness differences and saturation differences on the other, is a common source of trouble; and the uncertainty as to how far the reactor is expected to deviate from a perfect match is another serious matter. Some persons of normal color vision make as bad confusions in these tests as do some who are typically color blind.

3. In the pattern-tests, neither naming nor matching of colors is required. Stilling's test, which is the best known test of this type, consists of charts or plates composed of small discs or dots of carefully chosen colors. These dots are so arranged that in each chart numbers are formed by series of certain dots, differing perceptibly, for persons of normal color vision, in color or brightness from the surrounding dots. For the color blind, however, the dots composing the numbers on certain of the charts are indistinguishable in color from the surrounding dots, and hence the numbers are unrecognizable. This test has the virtue of detecting cases in which only the center of the eye is color blind, since if some of the dots composing the numbers fall on the color blind area, the number is unrecognizable.

The Ishihara test is similar to Stilling's, but has fewer plates, with some in which the numbers are recognizable by the color blind, but not by the normal eye.

Excellent as these tests are in theory, they are unsatisfactory for various reasons. It is apparently difficult to print or dye the exact color values which will distinguish adequately normal color vision from the milder degrees of color weakness, and these from the typically color-blind. The tendency of the colors to fade with use is also detrimental. These tests are the best of the standard tests for adults, but not satisfactory for children.

4. To avoid color matching difficulties, and yet retain the advantages of worsteds, the J. H. U. test was devised. In this test, thirteen sample skeins are arranged in a row, from right to left, on the far side of the table from the reactor. A large number of assorted skeins are heaped on the table, and the reactor is required to place each of these in a column under that one of the

sample skeins with which it most nearly agrees in color. There is, therefore, no question of a perfect match: it is merely a question of finding, for a given skein, which one of the samples agrees with it best. After the reactor has arranged all the skeins, he may correct the arrangement until he is satisfied. The arrangement may then be sewed to a sheet of cardboard for preservation. This test is very satisfactory for adults, but requires from one to two hours' time for each reactor, and hence is not practical for extensive testing.

To avoid the objections to the J. H. U. test, the Nela test was devised. In this test, the worsteds are permanently arranged in triplets, that is, three skeins side by side. The reactor is required to indicate whether the middle skein in each triplet agrees more closely in color with the skein at its right or the skein at its left. This test is capable of rapid application to children as well as adults, and the form now available detects the color weak as well as the color blind.

A color test must be given by an expert, under standardized conditions of illumination, and carefully controlled psychological conditions, or its results are unreliable. This applies even to the best tests yet devised. Variations in the instructions given the reactor, and in the routine of the test, produce variations in the reactor's judgments. The emotional tone aroused in the reactor is also an important factor. Under different lighting conditions, even when daylight is used, the colors of the test materials vary, because the composition of daylight varies. When tests are given carelessly or unintelligently, not only are confused results obtained, but also some normal individuals are made to appear color blind, and some color blind appear normal.

Certain measurements are useful as an auxiliary to tests of color blindness, and are of further importance as means of studying the conditions of these defects. For the red-green blind, the relative brightness of the various parts of the spectrum from red to blue-green differ from that of the normal eye. For the protanope, whose spectrum is shorter at the "red" end than for the normal eye, the visible "red" is relatively darker, as compared with the "yellow" or "green" than it is for the normal eye. Hence, by comparing the relative brightness of red and green

light for a red-green blind individual, it may be determined whether he is a protanope or deuteranope, even though no spectral light apparatus be available. For this purpose, a red and a green light, using colored glass or gelatine, are so arranged that the intensity of the green may be reduced either by graded series of smoked glasses, or by an episkotister. The green, at first much brighter than the red, is reduced until it seems just equal in brightness to the red. Measurements are made on normal eyes to standardize the scale of reduction, and the protanope may then be detected by the considerably greater reduction of the green-brightness required for a brightness match for his eye.

Since the protanope and deuteranope alike see only one hue from the "red" end of the spectrum up to the beginning of the blue-green, any spectral color within this range may be matched by any other in the same range, by proper control of the brightness and saturation of each. In using the spectroscope for measurement of these matches, it is necessary to have a means of reducing the brightness of the normally brighter of the colors employed, and for adding a little "white" light to either. Since, however, the colors seen from R to B G by the red-green blind are really combinations of R and C in balanced ratio, addition of blue is exactly equivalent to the adding of white.

If spectral light is not available, measurements may be made with Maxwell's discs of colored paper. Measurements of the relative angular amounts of two colors (*e. g.*, R and G) required to match a third (*e. g.*, yellow), may be made in normal persons, and compared with the measurements on color blind, using the same colors. D and W must, of course, be used to equalize saturation and brightness. In this particular case, the results are not so simple as they appear, since for the normal eye the equation of R plus G with Y is a color match, complicated by brightness and saturation differences, but for the dichromat it is a brightness and saturation match only, since practically all mixtures of R and G are the same color to him.[81]

[81] A striking comparison of normal with dichromatic vision may be made with two combinations of Maxwell's discs, one of orange-yellow with black and white, the other with either red or yellowish-green and black and white. With proper angular proportions, the combination may be made to match perfectly in color, for the protanope or deuteranope, but of course not for the normal eye.

§4. Auditory measurements.

Measurements of auditory functions are concerned with sensitivity in the auditory range, and with pitch discrimination; which latter is analogous to acuity of vision.

Instruments for the measurement of auditory sensitivity are called *acumeters* (sometimes, improperly, "audiometers"). These are of two types: noise-instruments and tone-instruments.

The noise-acumeters depend upon the sound of a falling ball or falling hammer, striking on a surface of ivory, metal or other hard substance. In some instruments, the sound intensity is varied by varying the *height* from which the ball or hammer falls, the instrument being kept at a standard distance from the ear. The measurements are made directly in terms of the height, in millimeters, of the drop of the ball or hammer. In other instruments, such as the Politzer acumeter, the height of fall is kept constant, and the *distance* from the ear varied. These instruments are useful for the detection of gross deafness of a general sort, but not for detection of slight defects, or the comparison of normal capacities. It is almost impossible to measure the sensitivity of a normal ear by such an instrument, since the absolute distance of the just perceptible drop of the smallest ball easily handled is very minute, for distances of a few yards from ear to instrument. Attempts to use greater height of fall, by removing the instrument to a greater distance from the ear, (100 to 200 feet would be necessary) introduces distractions which make the results quite unreliable.

The noise-acumeter would not be completely satisfactory, even if it were technically practicable. The noise includes a large number of simple tones, and there is no way of determining which of these components is heard, when the total noise is just above the threshold. It is known that sensitivity can be abnormally low in one part of the total range of auditory pitches, and normal or even hypernormal in other parts of the range. Hence, it is necessary to devise an acumeter, or a series of acumeters which will measure the sensitivity at different points in the range, that is; which will employ pure tones. Several investigators are now engaged in the attempt to develop such an acumeter, and success will undoubtedly be attained before long.

Acumetric tests are sometimes made by finding the distance at which words, or whispers, are audible. These tests are competent only to discover cases of extreme deafness, and are unreliable for other purposes.[82] It is impossible to give vocal stimuli of uniform intensity; and different syllables have different degrees of intelligibility. Such tests are best conducted out of doors, for indoors a word will often be more audible at a greater distance than at certain nearer distances, on account of sound-reflections from walls. Even with these objections overcome, the tests would not be of sensitivity solely, but of mixed sensitivity and acuity, since pitch differences enter largely into the discrimination of words.

The limits of tone (pitch) perception are measured by means of large tuning forks for the lower limit, and König's bars for the upper limits. The forks are adjustable for vibration rates from 16 to 64, by steps of single vibrations, the most useful set consisting of three forks, each adjustable by means of sliding weights, for a part of the total range. Measurement consists in finding the slowest vibration rate at which a *tone* (as distinguished from a series of puffs) is audible, and the fastest rate at which the tone is inaudible, the mean being taken as the threshold. The observation on very low tones is difficult, and the technique is not yet fully perfected. For the normal ear, the limit is certainly not lower than 16 vibrations per second, and not above 32.

The König's cylinders used to measure the upper limits of tone perception are usually tuned to vibrate, when struck with a steel hammer, in the pitches of the diatonic scale from c^4 = 4,096 v. s. to c^7 = 32,768 v. s.[83] This range is adequate for adults, almost none of whom can hear tones as high as 25,000 v. s., but

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82See Andrews, *American Journal of Psychology,* Vol. 15, pp. 14-56.

83The abbreviation v. s. means vibrations per second, where a "vibration" is understood to be the movement of an air particle, or any vibrating object, such as the prong of a tuning fork, from the point of rest (*i. e.,* the center of oscillation) to the extreme limit of its movement in one direction; back through the resting point to the extreme limit of movement in the other direction; and back to the resting point again. Unfortunately, in the French system of numbering vibrations, a "vibration" is the movement from the point of rest to one extreme, and back to the center again, which is just half of the total vibration as we count it. Hence, a fork marked "512 v.s." in the French system is really only 256 in our system. To avoid this confusion, some authors write "d. v." (double vibrations) instead of v.s., when they wish to indicate complete vibrations.

children can frequently hear the highest note of the set. For practical testing purposes, the set is quite adequate.

The method of measurement consists in striking the bars in succession, and requiring the reactor to tell whether he hears, or does not hear, the note of the bar. Brief preliminary training in discriminating the tone from the "click" of the blow is required, and careful technique, not only in sounding the bars, but also in securing proper conditions of attention, are essential. In expert hands, the upper pitch limit, in the scale of the instrument, can be determined both quickly and certainly, even in the case of a child. The determination is important, especially on children, since many who are normal in sensitivity for low pitches, are deaf for high pitches (that is, have an abnormally low upper pitch limit). Although they can hear words, they have difficulty, on account of this defect, in distinguishing words, because the consonants are obscure, since the characteristic sounds of the consonants depend upon the relatively high partials in their total sounds. It is characteristic of such auditory defectives, that they can understand whispered conversation very imperfectly, since whispers employ consonants without vowels.

Galton's whistle, a short pipe with an adjustable plunger, giving a gradation of shrill tones, has been used for the determination of the upper pitch limit, but its use is now generally abandoned because of its essential unreliability, even in the improved form designed by Edelmann.

For measurements of pitch discrimination, tuning forks are used. Two forks, mounted on resonant cases, are necessary, one (the variable) being provided with sliding weights, and scaled so that by proper setting of the weight it can be put exactly in tune with the other fork (the standard), or can be made higher or lower in pitch. By the use of carefully controlled technique, the thresholds for pitch difference above and below the standard may be determined in terms of the scale of weight-position, and the actual pitches corresponding to such scale readings may be determined by the simple procedure of counting the beats per second.

A variant instrumentation for pitch difference threshold determination provides for the use of a standard fork, and a series of forks varying by determinate steps above and below the standard.

Instead of having to adjust a "variable" fork to a determinate pitch, as in the procedure described above, the fork of the required pitch is selected from the series. This instrumentation is not recommended. With either set of forks, the essential procedure is the same. The "standard" is sounded, and then the "variable," after which the reactor is required to judge whether the "variable" was higher than, lower than, or equal, to the "standard." Although apparently simple, accurate determination of pitch difference acuity requires an elaborate and careful technique, which would be tedious to describe here.

Measurements of Absolute Pitch

The criteria of "absolute pitch" are somewhat vague. What is ordinarily considered as absolute pitch is the ability to name correctly a note struck on a well tuned piano, or other musical instrument, when the person tested has not heard or produced a musical tone for several hours preceding. In this case, the accuracy of judgment required is within one semitone. Whether in the cases of "absolute pitch" reported, the individual could distinguish a slightly flatted or sharped note from the true note in the system to which the individual is accustomed is not clear. Further work on such cases, with notes of pitch varying by different amounts from the pitches of the accustomed musical standards, need to be made.

Sometimes "absolute pitch" is understood as the ability to recognize the approximate pitches of successive notes sounded at random on a musical instrument. In one reported investigation, as many as 50 notes were given in a single series or test. In such a test, if the first note is correctly judged, the remainder could be estimated by relative pitch; and in any case, relative estimation, that is, ordinary musical pitch estimation, is a large factor in work by this method.

§5. Measurements of dermal sensitivity.

Touch sensitivity is measured in terms of the pressure exerted on a unit area of skin. Small weights of cork and other substances have been employed, but the most satisfactory procedure makes use of the *Von Frey Esthesiometer.* This consists of a horse-hair,

fixed in a handle at one end, so that the other end of the hair can conveniently be applied vertically to the skin. If such an esthesiometer is applied carefully, with pressure just sufficient to bend the hair slightly out of line, the pressure exerted on the skin is approximately standard, slight difference in the bending of the hair being of negligible effect. The pressure exerted may be measured by applying the hair, in a similar manner, to one pan of a delicate balance, shortening the hair until it gives the exact pressure desired. A series of such esthesiometers, covering the desired range of pressure by determinate steps, furnishes the means for threshold measurement. Sometimes a single esthesiometer, with a hair so inserted in a sleeve that the exposed portion of the hair may be shortened or lengthened at will, and the length read on a scale in millimeters, is employed.

In using either weights or the Von Frey esthesiometer, great care must be used in applying the pressure, as the force of the impact varies with the speed. A "weak" hair, forcibly applied, may be felt when a stiffer hair, carefully pressed down, will not, although the final pressure may be much greater in the latter case. The measurer, therefore, must acquire by practice a uniform speed of application. Since the dryness or moisture of the hair causes considerable change in the pressure exerted with minimal bending it is difficult to maintain calibration. Filaments of celluloid or some other substance might perhaps be employed advantageously.

For rough tests of pressure sensitivity, when measurements are not attempted, a variety of stimulators are employed. Tufts of cotton, wool, or camels hair brushes, are perhaps the most satisfactory. In the use of such means of stimulation, no distinction has been made between touch and tickle.

Tactual acuity, analogous to visual acuity, is measured by stimulating the skin simultaneously by two styli, with slightly rounded points, carefully applied. The threshold lies between the least separation at which two points are felt as two, and the greatest separation at which they are felt as one. The instrument used is the *two point esthesiometer* (formerly called merely an *esthesiometer)*, which has an adjustment by which the separation of the styli can be varied finely, and read directly in millimeters and

decimals of a millimeter on a vernier or micrometer scale. Great care must be exercised, in using this instrument, to make the contacts simultaneous and uniform in pressure. The technique is beset with still graver difficulties on account of the fact that very often a *single* stimulus will be "felt" as *two.*

Difference sensitivity for touch is measured by means of the *haptometer.* This is an instrument consisting of a system of levers through which a certain standard weight is applied to a definite area of the skin, and can be increased or decreased without jar, by the removal of counterbalancing weights of any desired size. Such measurements can easily be made on the fingers, hands and feet, but application to other surfaces is difficult because the instrument is cumbersome, and, working through gravity, must operate in a fixed position.

Sensitivity and acuity vary greatly in different skin areas, but do not vary together. While both are at a maximum on certain areas, such as the lips and finger tips, there are other areas, such as the temples, where sensitivity is high, and acuity low. In general, acuity is highest on portions of the skin covering the most motile organs (lips and finger tips), and lowest where the motility is least, as in the skin of the back.

Pain sensitivity of the cutaneous and sub-cutaneous tissues is measured by means of the *algometer,* or *algesimeter,* an instrument constructed on the principle of a spring dynamometer. A button or disc of standard area, on the end of the algesimeter, is pushed against the skin, the pressure being steadily increased until "pain" is reported by the reactor. The pressure, in grams, at the moment of producing pain, is read directly from a scale, over which a pointer moves as in a spring balance. For tests of pain sensitivity, where no measurements are required, a fine needle is commonly used, the point being pressed against the skin with approximately standard force. In this way points relatively algetic and analgetic may be located.

Pain sensitivity thus measured varies in different parts of the body, being greater where the thickness of the tissues between skin and bone is least, as on the joints and on the head. For certain areas, for instance the temples, sensitivity is greater in females than in males, and decreases with age in both sexes. Feeble

minded persons are less sensitive, in general, than normal individuals, and the more intelligent "normals" are more sensitive, in general, than the less intelligent, although there are many exceptions.

Thermal sensitivity may be determined in two ways: by the application of warm or cold objects to the skin; and by the application of radiant heat. The former method is almost exclusively used. In the simplest form of the method, *Blix cylinders* are employed. These are cylinders of brass or steel, a few centimeters in length, and tapering at the end to a flat surface, 1 mm. in diameter. These cylinders are heated, or cooled, by immersing in water at the proper temperature; then quickly dried; and the end-surface applied to the desired point of the skin. For more precise work, a hollow metal instrument, through which water at the desired temperature is constantly circulated, is employed. With either instrument, the period during which the stimulation is employed is important. Stimulations of a certain temperature which are ineffective for brief application, may be felt if applied for a longer time, presumably because of the transmission of heat to or from deeper or laterally distant parts of the tissues. Slight differences in duration of application of the stimulation at different points may have much to do with the specific location of the so-called "temperature points" on the skin.

Measurement of kinesthetic and other somatic forms of sensitivity are complicated and difficult, and a merely general description of it is unimportant. The thresholds for both passive and active movement of joints have been determined, and attempts have been made to determine similar thresholds for movements of rotation of the head, and for movements of the body as a whole. Measurements of difference sensitivity to resistance have been made chiefly by means of lifted weights, in terms of the series of weights lifted under standard conditions. A set of weights and weight-holders well adapted to the determination of resistance differences sensed through hand and arm are called *Fechner's Weights.*

Somatic and kinesthetic thresholds depend upon multiple conditions. Efficient technique in these fields remains to be developed. In the fields of the external senses, many types of measurement

other than those described have been made, and new methods and new technique are devised as the problems develop. But all strictly sensory measurements depend fundamentally upon the determination of stimulus thresholds, difference thresholds and sensory limits.

Methods of measuring sensitivity and sensory acuity on animals, and on infants and human beings of low intelligence, are properly described in treatises on animal psychology, child psychology and mental deficiency.

CHAPTER VIII

THOUGHT AND THOUGHT CONTENT

§1. Imagination and perception.

So far we have been considering only sense data and relations as perceived. But perception is not the only way in which we can be conscious of objects. We can *imagine* or *think of* things which are not "present to sense." At the present moment, I may look at the blue-covered match box on my desk: that is *perception.* Then I may close my eyes and still be conscious of the box: that is *imagination.*

The terms *thought of* and *thought about* are commonly used in slightly different applications. When I am conscious of the box chiefly as a detached object, rectangular in shape, dark blue on the ends and light blue on the sides, and with any other features which, if the box were perceived, could be present in a single "act" of perception, I am said to *think of,* or *imagine* the box. In that case, the relations of which I am conscious are mainly between different parts of the object itself. If, on the other hand, I am aware of the box as it is related to other objects: as a container for matches; as made from a thin sheet of wood by an ingenious machine; as costing, with the contained matches, one cent; as inflammable; and so on, I am said to *think about* the box. This difference between thinking of and thinking about will be more fully considered in a later section of this chapter.

Imagination and perception are closely related. In general, it is possible to imagine only what has been perceived previously. The medieval philosophers, from whom "common sense" theories are so largely drawn, held that the dependence is absolute. "Nothing," they said, "can be in thought which has not previously been in perception." Whether this sweeping generalization is or is not justified, we shall not attempt to decide until we have considered the important topic of instinct: but certainly there is some truth in it. The adult who has been blind from birth can-

not imagine light and color; the congenitally deaf man cannot imagine musical tones; and the anosphresic man cannot imagine the odors of flowers. Yet, as we shall see, constructive imagination is possible. An intelligent man who has never seen snow *may* be able to imagine it, if he has perceived cold, and white objects, and has noticed the differences between wet and dry objects, and has observed the possibilities of changing the characteristics of an object. Furthermore, men have succeeded in imagining things—such as the unicorn and the sea serpent—which no man has ever perceived.

On account of the close relation of imagination and perception, it has been customary to divide the topic into the same modal classes as the senses. Visual imagination is the imagination of objects which, if perceived, are predominantly visual: that is, those which include colors and brightnesses among their characteristics. The thought of sounds is called auditory imagination; the thought of odors, olfactory imagination, and so on.

Individuals differ in regard to their habits of imagination as modally distinguished. Certain persons think of the visible details of objects more often, or more clearly, than of their auditory details, or details of other modes. Certain others think predominantly of the auditory details. From the consideration of these facts we derive the distinction of *imaginative types.* The predominantly "visual" thinker is said to be of the visual type, or a *visile.* We have, then, theoretically at least, the *visile,* the *audile,* the *tactile,* the *gustile, olfactile, motile,* (kinesthetic) and other modal classes of imagination. Although no one would be supposed to belong strictly to one of these classes, but rather to imagine one of these sorts of sense data with greater ease, or frequency, or vividness than the others, the distinction has considerable theoretical interest.

We understand, then, as belonging to a certain modal "type of imagination;" as, for example, the "audile;" the person who either (a) imagines sounds more vividly than he imagines other sense data, or who (b) in thinking of an object which combines auditory data with other data, tends to think of the auditory data rather than the others. These tendencies apparently depend upon the capacities of sense perception, either in regard to sensitivity

and acuity, or upon habits of sensory attention. The man who, with all his senses normally efficient, habitually attends to visual features of the world, to the relative neglect of the other features, will, in his thinking, follow the same lines of habit, and be a *visile.* The man who is distinctly defective in some sense will not be of the imaginative type of that sense. If he is, and for a large part of his life has been visually defective, he will not be a visile, since he will attend more strongly to the other sense data, and will discriminate them more effectively. Or, we may put the facts in another form, and say that the person who is *defective* in any of his senses will not be highly developed in imagination of the corresponding mode: but nevertheless a man may have normal efficiency of a given sense, and yet neglect it perceptually and imaginatively.

The modes of imagination which are most highly developed, among people at large, are, as we would expect, the auditory, visual and kinesthetic; the modes in which perception is most complex and most highly developed. Taste, smell and touch, on the other hand, which are of less practical importance in civilized life, and in which, for the average person, perceptual discrimination is least developed, are the modes generally neglected in imagination.[84]

§2. Reproductive and productive imagination.

In imagining an object or an event, one may be thinking of a real object, which he has earlier experienced perceptually; or of an event which actually occurred in the range of his perception. Thus, I may imagine the flaming red automobile which buzzed by my window a few moments ago. I may imagine its color, form,

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[84]The term imagination is derived from *image,* a copy. Some of the ancient Greek philosophers supposed thought to be possible through the operation of copies of objects (eidola) which, although of extremely rarefied substance, yet preserved the form and many other characteristics of the objects from which they "emanated." These "eidola," floating about in the air, enter the brain on occasions, and are then objects of consciousness—*ideas.* This image-doctrine has persisted for several thousands of years, and even now it is widely believed that such "copies" of real objects exist, and that it is such a copy or copies of which one is conscious in imagination. As the doctrine of "images" is held at present, the images are not supposed to be of the same substance as the original object, but of a sort of mental stuff, which can imitate the aspects of reality.

No such "mental images" are assumed in the discussions of this book.

noise and passengers; and I may think also of the sequence of its passage: first the noise, faint in the beginning, and then louder, followed by the visible appearance; its turn at the corner, and subsequent disappearance. Now, if in my thinking, I follow the details as they occurred, although many may be omitted in my thoughts, the thinking is called *reproductive* imagination. The consciousness and conscious processes (not the content, or object) of the primary perceptual experience are "reproduced" in imaginative form.

I may, however, imagine the passing of the car in a way which did not actually occur. I can imagine the car approaching as it did, but appearing a dark green. I can imagine it stopping under my window, and two men alighting, who come to the window, ask about the road to the next town, and then re-enter the car, which drives on. This type is *Productive,* or *Creative Imagination.* As in the illustration given, it always has a basis in past experience. That is, it has a foundation in reproductive imagination. Experiences of the past are reproduced, but with changes in the time-order, and in the space-order, and in other relations.

In a general way, creative imagination may be described as the re-combination of elements of former experiences: the elements, or certain unit combinations thereof, are reproduced *as parts,* and the creative function consists solely in the re-combination. An old illustration may be given. In imagining a harpy, the body of a vulture is thought of, with the face of a woman. Both of these features are "reproduced." Both have been perceived. The combination of the two, however, for the man who invented the harpy, was "creative."

If we should apply the scholastic doctrine "nothing can be in thought which has not first been in perception," we should incline to say that the above description of creative imagination as a mosaic or synthesis of reproduced fragments is final. We must refuse to accept this simple explanation for two reasons: first, in the combination of reproduced factors, something more than mosaic, or patch work, results. The fragments are adapted to the purpose, and so modified, in order to produce a coherent whole, that in some cases no items can be found which precisely reproduce any of the parts of former experiences from which they are

drawn. Second, it is by no means certain that new materials, previously unperceived, may not be imagined. The definite facts of instinctive, unlearned reactions compel us to hold this view as possible. Even if no elementary sense data can be perceived without perceptual experience of them, the combinations of these sense data into concrete objects and the related systems of such objects may be thought of.

§3. Memory and anticipation.

When reproductive imagination occurs, it may involve *recognition.* That is, when I imagine some object or event which I previously experienced, I may also recognize it *as having been previously experienced.* The recognition may be definite; the content imagined may be referred to a "more or less" definite past date. Thus, in imagining the face and voice of a certain person, I may identify them as of a person seen-yesterday, or a person seen-at-9-o'clock-on-the-4th-of-July. On the other hand, the object or event may not be dated at all: I may not be able to identify the time except as past. The recognition in this case consists in the consciousness of a certain *againness.* I identify the imagined lady as seen at some indefinite time in the past, and nothing more. In any case, whether the recognition is definite or indefinite, the reproductive imagination with recognition is properly called *memory.*

The element of againness in indefinite recognition is obviously a relation of a simple temporal sort. In definite recognition, the time relation is more complex, and the relation of betweenness, with perhaps other temporal details, enters. But the recognition can become definite in ways other than the temporal. For example, the lady of my imagination can be recognized as *my sister:* a very complex relational situation is introduced there at once, and the content of my imagination is very definite. The recognized content may be definite in innumerable ways, but the usual relational factors involved, in addition to those of time and space, are relations of classification, or inclusion. An object (plant, animal, picture, etc.) is recognized as belonging to a certain class (rosacae, canine, Flemish school, etc.), the definiteness of the recognition depending upon the smallness of the class; *i. e.,*

the complexity of the relations. While the illustrations just given occur most readily in perceptual recognition, they may occur also in imagination.

Recognition in imagination, however complicated by other relations, must always involve, and be based upon the *again* relation. Regardless of the definiteness of the relation of an imagined content, it is not recognized *(re-cognized)* unless it is referred to some past experience.[85]

Pre-cognition is just as much a fact as is *re*-cognition. In the latter case, we identify a thought-process with a previous perception-process. In the former, we identify a thought-process with a future perceptual process. This forward-reference of an act of imagination is called *anticipation,* and differs from the backward-reference of recognition only in the time-factor involved.

The symmetrical nature of recognition and anticipation may be shown by very simple cases. Consider in imagination an ice-cream soda: it may be in one case thought about as the ice-cream soda you felt, tasted, smelled, swallowed and paid for an hour ago: in another case, it may be thought of as the one you will have an hour hence. The main difference, after all, is that the one thought causally depends upon the past perception, whereas the other thought causally influences the future perceptions.

In either case, the imagination may be erroneous. Many recognitions are false, and so are many anticipations. Not only do we fail to recognize in many cases of reproductive imagination, and fail to anticipate in many cases where the future actually is foreshadowed; but we anticipate events which never do happen, and we recognize events which have not happened.

One of the most striking types of false recognition in perception is that to which the term "illusion of the déjà-vu" is conventionally applied. Often one views a situation: a mountain landscape, a bit of village street, a corner of a room, or what not; a situation which he could not possibly have seen before; and yet he recognizes it. "Why, I have been here before! I have seen this before!" And yet the recognition is false. The same sort

[85]In the case of perceptual recognition, the usage of language is sometimes looser. Thus, in seeing a picture which one has never seen before, he may say that he "recognizes" it is a Rembrandt. But he means, really, that he recognizes certain details which he has previously perceived in other works of Rembrandt.

of false recognition of spoken words also occurs. In some cases, it is possible that the words have been heard before, and cannot be definitely recognized; in other cases, it is impossible to escape the conclusion that the recognition is erroneous.

Failure to recognize what is actually reproduced is a common affair. It reaches its most striking phase in unintentional plagiarism, where an author or dramatist imagines a plot, or a setting, or some significant details, without recognizing them as something he has read or seen. Of course, deliberate plagiarism does occur: and, moreover, striking coincidences have happened. Two composers might invent the same melody independently. But cases of coincidence and of deliberate imitation are undoubtedly infrequent as compared with *failure to recognize.*

§4. Images, ideas and concepts.

The content of which one thinks at any time may be a relatively simple object, such as a lead pencil, in which only the sense data and intrinsic relations are attended to. By intrinsic relations we mean those which subsist between parts of the object itself; whereas extrinsic relations subsist between the object and other objects. The content of such a thought, in which sense data and intrinsic relations alone are attended to, is called, in conventional terms, an *image.* It must be remembered that an "image" is not a thing; not a "copy" of some more "real" object: but is merely an abstract term for whatever content, of the designated sort, happens to be *thought of* at a given time.

In most thinking, however, extrinsic relations are involved along with the central content. A pencil is seldom thought of merely as a hexagonal form (or a cylinder); yellow (or some other color), on the surface; and tapering at one end to a black point. It is usually thought of as something to write with: which involves relations to arm movements, tables, paper and black marks. In this case, we have what is called an *idea,* rather than an image. An idea may accordingly be defined as *a definite object thought about as related to other objects.*[86]

[86]Some confusion is inevitable here, since the term "idea" is also applied to the thought, or consciousness, as well as to the content. In the case of the Concept, or General Idea, there is fortunately no such confusion, since the term "concept" is, and has always been, applied to the content, never to the consciousness.

The emphasis upon extrinsic relations, evidenced in the idea as compared with the image, may be carried to an extreme in which intrinsic relations, and sense data, are relatively insignificant. In thinking about "pencil," for instance, I may attend only slightly to color, shape, or size of such an object, but attend to the extrinsic relations which *any pencil* will have: the essential relations to arm movements, writing surface, and black marks. The content in this case is a *general idea* or *concept,* and the act of thinking of a concept is *conceiving.*

The unfortunate confusion over the nature of images, which still persists in some psychological discussions, may be made less dangerous if we compare it with the earlier confusion over the nature of the concept, embodied in the philosophical discussions of the middle ages. Certain philosophers maintained that the concept or "Universal," as it was called, was a real thing. That, for example, there was a real Universal Table, in addition to the innumerable individual tables: otherwise, it was asked, how could one think of "table in general" rather than of some particular table of a definite color, size, and number of legs? How, further, can we think of Man, instead of just some particular man, unless Man actually exists? Other philosophers went to the opposite extreme and declared the universal to be a mere name, capable of being applied to a wide range of particular individuals.

Of course, there is truth—incomplete—in both extreme views, but both were over-stated. The concept is an actual fact: a real system of relations, although not a thing: and the name we give a concept (whether a concept of Man or a Table) designates a system of relations applicable to a number of particular objects. Now, the "image" has just as much reality as the concept, and no more. The image is not a thing, distinct from physical things, but is some object, or objects, *as thought of.* The green creeper and the red bricks which I now see through my window are real objects: but when I close my eyes and imagine them, the same identical creeper and bricks are called *images;* which means merely that now they are imagined or thought about, instead of being perceived. If this point is considered with sufficient care, we shall not be in danger of accepting the popular view of "images" and

"ideas" as a special kind of object, existing in the mind as does furniture in a parlor.

Since, after all, the difference between image and idea, and between idea and concept, are matters of degree, in spite of the considerable difference between image and concept, due to the relative importance of the sensory content in the former, it is a useful custom to use the word "idea" generally for all three, to avoid the repetition of "image, idea, and concept" when we wish to include all these types. Hereafter, therefore, where the term "idea" is used without qualification, it will indicate any or all three types of thought content, as the case may be.

§5. Symbolic thinking.

Much thinking goes on without ideas being thought of. If I am asked "what weed is burned for the purpose of inhaling the smoke," I reply "tobacco," and have neither image, idea or concept, of the plant or its products. From that point I can go on through a consideration of the agricultural, economic, and physiological aspects of tobacco-growing and use, merely using words with very little more thought-content than is involved in the first step. Ideas do occur, however, at various points in this thinking process, and at any point I could break the chain, and substitute ideas for words. In general, it is more efficient to depend upon words as fully as possible.

This sort of thinking, by the use of words *or other equivalent acts,* is *symbolic thinking.* The essential principle involved is exactly the same as in an algebra problem, where w may stand for sheep, y for horses, and z for calves; and if these symbols are used in a regular way, we proceed as far as necessary with no further attention to the things they represent. The detailed nature of symbolic thinking cannot be understood until reactions and habit formation have been discussed. The topic is introduced at this point so that the acute reader of the section on ideas may not misunderstand the presentation given therein.

§6. The determination of imaginative types.

In the past, much interest has attached to the problem of determining the predominant imagination-types of individuals. This work, of course, belongs to Individual Psychology, but has re-

ceived serious attention from a number of general psychologists, chiefly because of its intrinsic fascination to the man of scientific curiosity. It has received very little attention from the workers in strictly Individual Psychology, because in the first place, there is no practical use which could be made of the determinations, if such determinations were possible (workers in mental measurements are for the most part persons of intensely practical bent); and secondly, because, unfortunately, accurate determination has not been found possible.

Several test-methods have been proposed, the one most largely used being the direct observation method of Francis Galton, who was the first to become interested in this problem as he was in several other problems of individual psychology. Because the method usually requires the answering of a carefully drawn set of questions, it is sometimes called the "questionary method," but this term is not accurately descriptive.

A series of observations illustrative of the method may be made as follows:[87]

FIRST METHOD. SIMPLE REPORT.

Imagine a pan of onions frying on a stove:

(a) Can you see the onions in imagination? What color are they? What sort of a pan can you see? In what position does it sit on the stove? Are you sure you *see* the details described, or do you think them in words, or in some other way?

(b) Can you hear the onions sizzling in the pan?

(c) Can you smell the odor of the onions?

(d) Imagine some of the onions put into your mouth. Can you feel (tactually) them? Are they sensorially hot? Are they salty, or do they need salt? Can you imagine them as overly salted, and taste the salt?

(e) Imagine yourself grasping the handle of the frying pan to lift it off of the stove. Can you "feel" the handle (tactually: thermally)?

(f) Do you "feel" the shape of the handle? The weight of the pan and contents?

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[87]For a longer and more detailed set of instructions and questions, see Titchener, *Experimental Psychology. Student's Manual, Qualitative*, §51.

(g) Think (imagine) the word "onions." Do you hear it? See it (in written or printed form)? Or feel it (feel the saying of the word)?

The observations demanded by such a set of instructions and questions are apparently simple, and it may seem a simple matter to obtain accurate answers to the questions. But in reality, very complex processes are involved in the observations, and it is difficult to obtain reliable information in this way. The whole matter of reaction and habit formation needs to be understood before we can even explain how it is possible to obtain an accurate report on any observation; and these observations offer as great difficulty for accurate reporting as any we are called upon to make. Mere practice in such attempts at analysis, instead of increasing the accuracy, uniformly decrease it. Experimental attack is necessary to indicate the sources of error. The following set of instructions will help to illustrate.

1. In imagining the visual aspect of a pan of onions, try (a) with exact fixation of the eyes on a point on the wall, (b) with no restraint on the fixation, neglecting the eye movements. In which way can you "see" the onions best?

2. In imagining the odor of the onions, (a) hold the breath, or else, having taken a deep breath, let it slowly out as you try to imagine the smell, (b) instead of holding the breath, or exhaling "sniff" *i. e.,* inhale sharply with constriction of the nostrils. With which method is the odor imagined most clearly?

3. In trying to imagine the taste, heat, and touch of the onions in the mouth, (a) depress the tongue and hold the lips and cheeks rigid; (b) allow the mouth, lips, and tongue to move without restraint. Which method gives the best results?

4. In imagining the "feel" of the pan handle, and weight of the pan, (a) hold the hand and arm rigid; (b) let the hand and arm be at ease. Can the "feel" and weight be imagined as readily in the first case as in the second?

5. In imagining the word "onions," if it seems "visual" when no eye restraint is employed, try the effects of fixation. If it seems audible, try rigidity of the mouth, tongue and vocal cords: or put the vocal organs in the position of saying *a* (as in rat), and try to imagine the word under such conditions.

6. When imagining sounds which seem clearly "heard" in imagination, observe whether there are distinct changes in tension in the muscles within the (middle) ear.

7. Observe carefully the vocal accompaniments of the imagining of visual, olfactory and other sensory details. Also, inhibit vocal movements in such cases, as instructed under (5) above.

As a result of such observations, the following conclusions will be strongly suggested:

I. The "visual," "auditory," "olfactory" and "gustatory" characteristics of objects imagined are to a considerable extent due to kinesthetic processes involved in adjustment of the corresponding sense organs. The "visual" characteristics, for example, are due to adjustments of the eye *as if seeing:* the "olfactory" characteristic to adjustment of the breathing and nasal muscles *as if smelling,* and so on.

II. Kinesthetic processes are highly important in verbal imaginations. The words are "thought" through processes involving actual slight movements of the vocal organs.

III. In many cases, imagination of various apparent modalities turns out to be *verbal* thought accompanied by sense organ adjustments as described under I. In other cases, movements of the arms, legs, fingers, or other parts of the striped muscular mechanism are involved.

Second Method. Verbal Style

It has been supposed that the writings of an author may give a clue to his imagination-type. Poe, who used sound words so lavishly (see *The Bells*), is supposed, therefore, to have been of the audible type. Other authors, who seldom describe or mention sounds, but revel in visual description, are supposed to be of the visile type. An author who uses names of odors, who refers to odor perception, and who describes odorous substances copiously, would be said to be of the olfactile type.

While it is true that the material used by an author indicates the lines of his interests in a general way; that one who writes much about color, for instance, is keenly interested in color, and influenced greatly by color perception; this gives no information

as to how the author thinks of the sensuous data in which he is so interested. Poe may have thought of sounds in a purely verbal way, and Amy Lowell may think of colors and visual objects in the same verbal manner.

Third Method

This method attempts to obtain more accurate reports, by presenting material to the reactor for memorization for a specific length of time, in order that a report may be made on the processes occurring during perception as well as during recall. In one form of this method, letters, arranged in regular rows and columns, are presented (as in Binet's Letter Square Method), and the R is required to learn the letters, and to reproduce them afterwards in the original arrangement, if possible. R is required to report on his method of learning, and on the "images" in recalling. Sometimes inferences as to the efficiency of visual imagination are made also from the tendency of R to recall letters correctly, but to place them incorrectly, on the assumption that with good visualization of the whole group, the letters will be "seen" in their proper place, if at all.

In other forms of this method, words, geometrical figures, colors, and various diagrams and pictures are presented; or words and tones presented acoustically; or tactual, thermal, algetic and kinesthetic impressions produced; as a basis for report. This method has the virtue of being experimental, and may, perhaps, give more reliable results than does simple imaginative observation, although many of the same sources of error are present.

§7. The cultivation of imagination.

It might be supposed that the determination of imagination types would have a certain practical value, in addition to its attraction for mere psychological curiosity. It has been assumed, indeed, to be important to determine the type of an individual, especially a child or adolescent, in order, *first,* that material for learning (school material, for example), should be presented to the sense (vision or audition) in which the thought-facility of the individual is greatest; and, *second,* that training in imagination might be given in the modes in which the individual is deficient.

The first proposed application of type-determination, even if possible, would be a round about way of getting at something which can be more simply approached. The practical question as to which method of presentation, visual or auditory, best suits the child's needs, can be determined only by finding in which way the child actually learns best, by testing him for speed and accuracy of learning, as well as for retention; and not by bothering about the sort of "imagery" he uses in reproducing.

As regards the second point: the dependence of imagination upon perception is such (as will be shown in later chapters) that the only way of increasing the facility of thought of any class of sense data is to increase the *attention to* and the *discrimination of* that sort of data in perception.

Determination of the modality of imagination is useful in order to discover the habits of perception upon which imagination is based. But in any case, it is a determination simply of the *kind of objects one thinks about,* and not of *how one thinks of them.* The latter question can be answered only by a thorough analysis of the process of reaction and habit-formation, not by simple observation or so-called "introspection." It is the confusion of these two problems which has in the first place made the topic of types of imagination seem unduly important, and in the second place, made it seem unduly complicated and hopeless of solution.

CHAPTER IX

THE BODILY MECHANISM

§1. The complex organism a social group.

The body of a human being is made up of a vast number of *cells,* together with certain structures and fluids manufactured by certain groups of these cells. Among these manufactured products are bone, cartilage, hair, nails, the lymph and the plasma of the blood. The cells are *living;* the structures and fluids mentioned are *non-living,* but are essential to the life of the body, and the life of its cells.

The relations between the cells and the cell-products which make up the body are strikingly like those existing in a swarm of bees. The bone, hair, lymph and other non-living parts of the body may be likened to the combs, honey, and bee bread: the individual cells to the bees. Each cell in the body is a distinct, living individual: it could, if proper conditions of food, moisture and temperature were supplied, remain alive and even grow, although isolated from the other cells. In fact, cells from lower animals have been kept alive, and have thrived, in artificial cultures. So a bee may live when separated from the swarm.

Under ordinary conditions, however, the life of the bee depends upon its being a part of a swarm; and the life of a cell depends upon its being a part of an animal body. The swarm is made up of groups of individuals having functions which are contributory to the life of the whole swarm, although no one group performs all the necessary functions. The queen, after fertilization, deposits eggs in cells prepared by the workers and does nothing else, except maintain her own vital functions. Certain workers care for the eggs and larvae; others gather honey or pollen; others prepare the "bee bread;" and others make and care for the comb. The labor of each group so supplements the labor of the others that the total functions necessary for the life of the swarm are accomplished.

In a similar, but more highly specialized way, the various

kinds of cells in the animal body perform functions which mutually supplement one another. Some cells merely protect the body from outside forces; some secrete saliva; some manufacture gastric juice; still others elaborate other digestive fluids, which are needed to transform food which has been eaten into materials to nourish the whole array of cells. Certain cells, (muscle cells) merely contract and expand: but in the abeyance of their function, digestion, circulation and respiration could not go on, and all the cells in the body would die. Some cells do nothing but transmit impulses from one part of the body to another; others floating in the blood stream are merely conveyers of oxygen; and still others roam about through the body, devouring enemy cells. The list of specific, indispensable functions, carried on by specialized cell groups, is a long one.

All of these cells, with their diverse functions, cooperate in a most efficient way, or the whole group perishes. Because of this cooperation, the body is an *organism* or *individual,* instead of a mere colony or mob of minor individuals. Nevertheless the individual cells are the life-units, and the body is a *society* of these individuals; the individuality of the body is just its high degree of *social organization* of the constituent individual cells.

Just as the organization of individual cells makes up the *complex animal,* so does the same sort of organization of insects and animals (bees, wolves, or men) make up a still higher individual, the swarm, pack, or social group. The relation between a man and the constituent cells in his organism is precisely like that between the highly trained army division and its constituent men, *except,* that in the animal body there are no *commanding* cells, but the whole is organized as an intricate *republic.*

The unity of the complex animal organism lies in its functions. Structurally your body is a conglomerate of myriads of units. But the whole group act in such interdependent ways that the actions become actions of the group as a whole. It is true that there is a *mental unity* connected with the organism, but this again is dependent upon the social action of the cells. Consciousness has as its organic condition not the function of any particular cells, or particular group of cells, but the *synthetic* or *integrative* action of several large groups of cells.

§2. The living cell.

Every animal, and every plant, is either (1) a single cell, or (2) a group of cells, with certain cell products. For the study of animal function, therefore, it is necessary to have an elementary knowledge of the nature of the cell.

The substance of the cell is known as *protoplasm,* and is of varied chemical composition, according to the kind of cell. The complete cell has a *nucleus,* or sometimes, as in the striped muscle cell, a number of *nuclei;* from which the remaining protoplasm of the cell is distinguished by the name *cytoplasm.*[88] In many cells, a single nucleus is surrounded by a layer of cytoplasm. In some, the nuclei lie on the outer surface of the cytoplasm. The cytoplasm of various types of cells receives special names: *sarcoplasm* in the muscle cell: *neuroplasm* in the nerve cell, and so on.

In complex plants, the cells secrete a substance which forms cell walls, enclosing the cells: the formation of these being much like the formation of an oyster's shell; and like the shell, the cell wall is non-living. In the animal there are no cell walls, but many cells are wrapped in delicate connective tissue membranes, which are produced, not by the cell so wrapped, but by a special type of "connective tissue" cell.

Cells are of various sizes and forms, but in general *microscopic* in cross section, although some may be (in the human and other large animals) several feet in length. Many types of cell in the complex animal are of compact shape—cuboidal, or disc-like, or of short cylindrical form, or of various irregular shapes approaching these—and the *unicellular* plants and animals are most generally of compact form. Some of the free-moving unicellular organisms have cytoplasmic "hair" or *cilia,* as do certain "hair cells" in the complex organism. Many unicellular animals have the power of changing their shape, and so do *muscle cells* in the complex animal.

In the nucleus is found the *chromatin,* which is the important substance in the hereditary transmission of characters from parent cell to "daughter" cells, and so from organism to organism. Growth and development in the cell itself, and the manufacture

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[88]Both nucleus and cytoplasm are protoplasm, although in any given cell they differ from each other chemically and structurally.

of substances to be "secreted" (the secretions of the various gland cells, etc.), are controlled by the nucleus.

Every cell in the complex animal body is descended from a single cell: the *fertilized egg.* In fertilization, the nucleus of a spermatozoon or sperm cell (male germ cell) enters the ovum (egg) and unites with the nucleus there to form a single nucleus. The egg then divides by *mitosis,* to form two cells; these divide in the same way, and so on, each generation doubling the number of cells. As the cells become numerous they form first a solid mass, the *morula;* this then enlarges and becomes a hollow vesicle, the *blastula.* Up to a certain point in this process of cell-multiplication, all the cells are exactly alike, and exactly like the original fertilized egg. If, for example, the two cells resulting from the first division of the fertilized egg are separated without injury, each will develop into a complete animal, the two almost exactly alike. Even at a later stage, when four, eight, or more cells have been produced, division of the mass of cells into two groups of equal numbers may, in the case of certain animals, produce the same result. So-called "identical twins" are probably produced in one of these ways.

At a certain stage in the development, the cells begin to be differentiated; and only a small group retains the likeness and potentialities of the original fertilized egg. At what point in development this differentiation begins is not certainly known, but there is evidence of it in the morula, in which the inner cells seem to differ from the outer layer. In the blastula, three types of cells are discriminable, and there are undoubtedly more. The three types form three *germ-layers:* the *ectoderm* (outer layers), *endoderm* (inner, or lining layer) and the *mesoderm,* which lies between the two, but does not always form a complete layer.

With continuing multiplication of cells, differentiation of the cells increases, and the cell group begins to assume the form of an animal. From the fertilized egg through the blastular stage, the new animal is known as the *embryo;* but as it begins to assume a form like that of vertebrate animals, it is known as the *foetus.* The human foetus looks not very human at first, but in approximately seven months' time the multiplication and differentiation of cells has reached the point of producing an infant, capable of

independent existence, but not fully prepared for separate life until two months later.

The complete human animal includes essentially cells of nine classes, differing markedly in structure and function. These are: muscle cells, nerve cells, gland cells, epithelial cells, connective tissue cells, bone cells, cartilage cells, blood cells and germ cells. Within these classes there are further almost innumerable important differentiations. These cells are named for the *tissues* of the body in which they are the essential components. But each of these tissues actually contains from four to all of the types of cells. Blood cells are found in all of the tissues; connective tissue cells, and their products, are necessary parts of glands, muscles and nerves; and nerve cells penetrate muscles, glands, connective tissue, cartilage and bones.

The germ cells in the body are in the testes of the male and in the ovaries of the female. They are the only cells not differentiated in type from the original fertilized egg from which the whole body developed. Either in the male or the female, they are practically exact copies of the parent cell (the fertilized egg) from which the body developed. These germ cells, by a process of reduction-division, produce spermatozoa in the male, and eggs in the female, which are incapable of reproduction until a sperm nucleus penetrates an egg and unites with its nucleus.

One type of bone cells, *osteoblasts,* (literally "bone-builders") produce bone by secreting it, as an oyster secretes *nacre* (mother of pearl). They work from the center of the bone outwards, and are followed by another type of bone cells, the *osteoclasts* (literally "bone destroyers"), which eat the bone, and so render the bones hollow. Cartilage cells secrete cartilage in much the same way, but as there are no "cartilage eaters," cartilage is solid.

Blood cells are of two general types: *red blood corpuscles* (erythrocytes), and white blood corpuscles (leucocytes). The former are produced by parent cells in the marrow of certain parts of the bones. As they soon lose their nuclei, their span of life is brief and they are finally filtered out of the blood and destroyed in the spleen. During their life-time they float in the blood stream and are mere carriers of oxygen from the lungs to the various tissues of the body. White blood corpuscles are of several kinds,

but some kinds, at least, are like independent animals, having the power of crawling, like the amoeba; and hence they may leave the blood stream and penetrate the tissues. These leucocytes actively attack bacteria, and devour them. For this reason they are called *phagocytes* (eater-cells).

Connective tissue cells manufacture and keep in repair the fibers and sheets of which connective tissue is largely composed. The ligaments which bind the bones together at the joints; the tendons which connect muscles to bones; the *fascia* (broad sheets lying between the skeletal muscles and the superficial tissue—and between certain layers of muscles); and the mesenteries which support the intestines, are strong tough strands and sheets of connective tissue. The delicate wrappings of nerve cells (neurilemma) and of muscle cells (sarcolemma); and the somewhat denser perimysia and perineurea which bind muscle cells and nerve fibers respectively into bundles, are connective tissues, produced and maintained by connective tissue cells which live in between the muscle cells and between the nerve cells.

Epithelial cells compose the epithelia which cover the skin, and line the various passages of the body. The function of these cells is, in general, protective. Certain epithelial cells, however, have become specialized to act as *receptors* (which will be described later), while others have become gland cells.

Gland cells are found not only collected into glands, but also scattered singly in various epithelia. The gland cell has the highly developed capacity to manufacture certain substances (such as mucus, digestive juices, or epinephrin) which are not needed directly by the gland cell, but by the organism at large.

In certain glands, such as the kidneys, the function is not really one of manufacture, but merely of separating from the blood certain substances such as urea which the blood brings to them. The layers of epithelial cells in those organs act as filters. In other glands, such as the liver, pancreas and adrenal glands, the process is actually one of manufacture of new substances from materials taken from the blood stream.

Muscle cells are of three kinds: striped muscle (also called *striated, voluntary* and *skeletal);* smooth muscle *(involuntary* and *visceral);* and cardiac muscle. Striped muscle is in general con-

nected to the bones; it is the muscles of the arms, legs, neck, face and trunk. Smooth muscle forms part of the walls of the alimentary canal (gullet, stomach, intestines): of the blood vessels (veins and arteries); and of the ducts of various glands, including the urinary passages. It is also found in connection with the hair follicles, each hair follicle having a muscle attached. Cardiac muscle is found only in the heart. It is striped, but non-voluntary, and is further distinguished by being a syncytium, in which the different muscle cells have anastomosed, or united in such a way that they cease to be distinct individuals. This is the only part of the body in which cells lose their distinct individuality.

The function of muscle is to *contract* and *relax*. By this simple function of shortening and elongating, a vast amount of complicated work is done. The animal moves its members, moves its whole body, breathes, obtains food and drink, chews and swallows, digests and excretes waste products, maintains the circulation of blood, defends itself from enemies, and effects sexual intercourse, through the nicely adjusted contractions and relaxations of its myriads of muscle cells. As far as reaction and adjustment to environment are concerned, the processes are immediately dependent upon the muscle and gland cells, which are hence called *effectors*.

The difference between voluntary and involuntary action need not be discussed at this point. While it is in general true that skeletal muscle is voluntary in its action, and that smooth muscle and cardiac muscle are involuntary, there are numerous exceptions. All striped muscles are capable of involuntary action, as well as of voluntary, and they often exhibit finely coordinated involuntary action. Certain smooth muscles of the genital system (surrounding the urethra of the male and the vagina of the female) although characteristically involuntary in their action, may readily be voluntarily contracted. Certain persons can slow the heart beat "voluntarily," and can "voluntarily" secrete tears and saliva.

§3. The neuron.

Nerve cells are the essential elements of the brain, spinal cord, nerves and ganglia. The typical nerve cell has two or more long

fibers of cytoplasm, although some have but one. The cell as a whole is called a *neuron;* the part containing the nucleus, and from which the fibers grow, is the *cell body.* The neuron, or nerve cell, is then the cell body *plus* the fibers.

Neurons have, so far as is known, but one function, aside from that of self-nutrition. This function is variously described as *discharge, production of nerve current,* or *transmission of irritation.* The neuron can be stimulated or excited, either by another neuron, or by a physical stimulus; and can, upon such stimulation, "discharge," or so act as to stimulate another cell, which may be another neuron, or a muscle or a gland cell.

If we have a series of neurons, with a fiber of the first in contact with a fiber of the second; a fiber of the second in contact with a fiber of the third, and so on: and if we stimulate the first neuron properly, it will stimulate the second, the second will stimulate the third, and so on. Obviously, some "process" passes through the neuron, passing into the cell body through one fiber, and out through another: because a neuron excited at the tip of one fiber will excite another neuron with which another of its fibers is in contact. This "process" is called "nerve current." Its exact nature is unknown, and is the subject of various theories, but it is analogous to the burning of the powder in a fuse. Suppose we lay a number of short pieces of fuse end to end, and light the free end of the first. The combustion process will run through the first piece, ignite the second, and so on through the whole line. Yet nothing travels, except the process of combustion. The chief differences between the action of this line of fuses, and the action of a chain of neurons are that the neuron has a rapid recovery, becoming quickly ready for another discharge; and that the neuron, in many cases, has numerous branches of its fibers in contact with many other neurons, and stimulates, at a given discharge, some of these without stimulating the others.

The neuron fibers are of two kinds: *axons* and *dendrites.* Each neuron has an axon; it may have no dendrites or may have one or many. The axon[89] normally conducts nerve current away from the cell body, the dendrite towards the cell body. The dendrite

[89]Frequently written axone.

therefore receives stimulation from another cell: the axon applies stimulation to another cell. But the cell body may receive stimulation directly from the axon of another cell without employing a dendrite.

The method of connection of nerve cells may be understood most easily by considering it from the point of view of the axon. Branches of the axon touch other nerve cells functionally in two ways: (1) they touch branches of the dendrites of another cell, or (2) they touch the cell body of another cell, in the latter case usually surrounding the cell body with a network of axon-branches. In either case, the point of contact between the axon branch and the other cell (body or dendrite) is called a *synapse.* A synapse, then, is the point at which an axon of one neuron touches and can stimulate the dendrite or cell body of another neuron.[90] The synapse is supposed to be the "valve" which permits a discharge in but one direction through a neuron. The stimulation can pass from the axon to dendrite or cell body of the next cell: but the synapse will not permit of a back-flow. Hence, in any neuron chain in the body, neuron 1 can stimulate neuron 2, and neuron 2 can stimulate neuron 3, and so on; but neuron 3 cannot stimulate neuron 2, nor can neuron 2 stimulate neuron 1.[91]

All neurons may be stimulated "inadequately" by an electric current. Certain neurons, however, have apparently developed the capacity for being stimulated by certain forces to which other nerve cells do not respond. Thus, the rod cells and cone cells in the retina of the eye are stimulated by light. The olfactory cells are stimulated by odorous gases, and so on. These specialized cells are called *receptors:* and their specialization is the only form of differentiation of function in *kind,* which has been discovered among nerve cells. Aside from the receptors, all nerve cells have

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90The axon may "touch" other cells at many places at which no stimulation occurs; just as a well insulated electrical wire may cross or touch many others, but will make "electric" contact only at its exposed tip where the insulation has been removed.

91Hence, when the distal part of an axon branch is stimulated inadequately, "current" may flow back in the axon towards the cell-body and out through another branch of the same axon, to another neuron (the so-called "axon-reflex"): but not through any of the dendrites of the first cell or through its cell-body to axons in contact with them.

the same function,[92] namely: to be *stimulated* by a preceding cell, and to stimulate in turn a following cell.

§4. Epithelial receptors.

Not all receptors are nerve cells. The receptors for taste, the receptors for hearing, and the receptors in the vestibule and semicircular canals are modified epithelial cells. Each of these epithelial receptors is touched synaptically by branches of a dendrite of a nerve cell, to which it passes the stimulus. The receptors in the three divisions of the inner ear are "hair cells," that is, have cilia growing from their free surfaces, and it is apparently by the literal "pulling" of these hairs, through the movements of jelly-like structures to which the distal ends of the hairs are attached, that the stimulation occurs.

§5. The divisions of the nervous system.

The terminology of the nervous system is complex and confusing. Strictly speaking there are two "nervous systems," (1) the general system, involving the brain, spinal cord, many ganglia, and the nerves of the soma, viscera and special sense organs; and, (2) the local system of the alimentary canal (known as the plexus of Meissner and Auerbach) which has a certain relative, not absolute, independence of the general system. It is common, however, to distinguish (1) the Central Nervous System, including the brain, spinal cord and certain ganglia lying close to the cord and brain, and (2) the Peripheral Nervous System, including the nerves, except those connecting with the viscera and (3) the Autonomic System, which includes the nerves connecting the cord and brain with the viscera, and certain ganglia connected with these nerves. Sometimes the "Central Nervous System" is taken as including (1) and (2) above.

Aside from the local alimentary plexus, there is really but one "system," with three divisions: afferent, efferent and central. It is especially important to remember that the so-called Autonomic System (including the Sympathetic System) is not in any wise

[92] A saving clause should be inserted here in regard to the motor cells in the medulla, etc., which seem to have the capacity for periodic discharge, independent of stimulation in the usual sense. In this respect, perhaps, they may be said to have a different *kind* of function from other nerve cells.

independent of the "Central System," but bears the same functional relation to it as does the so-called "Peripheral" System.

The peripheral and autonomic (visceral) divisions of the nervous system are made up of *afferent* neurons, which conduct nerve current towards the brain and spinal cord, and *efferent* neurons, which conduct current away from the cord and brain. The last neuron in any afferent chain or series, either enters the spinal cord through a *spinal nerve,* or enters the *brain stem* through a *cranial* nerve. Similarly, the efferent neurons leave the spinal cord or brain stem through the spinal or cranial nerves. These nerves are composed (aside from their connective tissue wrappings) of axons of efferent neurons and dendrites or axons of afferent neurons.[93]

The brain stem is composed of the medulla, pons, and thalami, with certain attached structures, and is exclusive of the cerebrum (cerebral hemispheres) and cerebellum. The brain, therefore, may be divided into cerebrum, cerebellum and brain-stem. No afferent neurons or efferent neurons connect directly with cerebrum or cerebellum: all peripheral and visceral connections are with the brain stem or the spinal cord.

Neurons lying wholly within the brain or the cord, or extending from brain to cord, are called *central* neurons. The central neurons are further divided into three classes: the *commisural neurons,* which extend from the right to the left hemispheres of the cerebrum, from the right to the left halves of the cerebellum, or *vice versa;* or which connect the two sides of the spinal cord or of the brain stem at the same level: *associative neurons* which connect different parts of the same hemisphere, or the same side of the cerebellum, cord, or brain stem: and *projection* fibers, or *ascending* and *descending* fibers, which connect cord with brain stem, brain stem with cerebrum or cerebellum, and *vice versa.* These are broad distinctions, and many cells in the brain-stem obviously are not to be classed in any one of these groups.

Afferent neurons fall into three general classes. (1) Those which are receptors, and whose axons enter the cord or the brain stem. Such are the receptors for the dermal, kinesthetic, and vis-

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[93]Only in the optic nerve, and the so-called olfactory nerve, are afferent axons present. In all other nerves the afferent fibers are dendrites of afferent neurons.

ceral senses. These have their cell bodies in the spinal ganglia, or in certain equivalent cranial ganglia. Their dendrites extend to the structures (skin, muscles, alimentary canal, etc.) whose sensitivity they serve; and their axons enter the cord or the brain stem. The complete afferent pathway in such cases involves but a single neuron. If the finger is stimulated, the nerve current produced by direct stimulation of a dendrite in the skin is transmitted to the spinal cord through a neuron which extends the whole distance from skin to cord. The olfactory receptors really belong in this first class of afferent neurons, since the olfactory bulb, into which the axons of the gustatory receptors extend, is strictly to be considered as a part of the brain stem.

(2) In a second class are those afferent neurons which extend between an epithelial receptor and the brain stem. These occur in connection with the hair cell receptors for the inner ear, and the taste receptors. In these instances, the epithelial cell is first stimulated; and in turn it stimulates the afferent neuron, which conducts the stimulation to the brain stem.

(3) In a third class are the afferent neurons of the visual sense. In this case, three successive neurons—a receptor and two intermediate neurons—are required to transmit the afferent current to the brain stem. Two of these neurons lie wholly within the retina. The third sends its axon through the optic nerve to the brain stem. This case is peculiar, in that the second and third neuron are considered as really belonging to the central, and not to the peripheral system. The practical importance for vision of the retinal arrangement is not known. All afferent neurons are bipolar cells: neurons with one axon and one dendrite. Almost all other nerve cells are multipolar, although there are a few unipolar cells.

In the case of the efferent neurons there are two classes: (1) Efferent current is sent to striped muscles through a single neuron, whose cell body lies in the spinal cord, or brain stem, and whose axon extends to, and has its branch in contact with, the muscle cells involved. (2) Efferent current is sent to smooth muscle and to gland cells, over relays of two cells. The first neuron has its cell body in the brain stem or cord, and its axon extending to a ganglion, in which it forms a synaptic connection with a number

of neurons, the axon of each of which extends to the muscles or glands, and ends in contact with the muscle cells or gland cells. The latter are the *post-ganglionic* cells: the former are the *pre-*

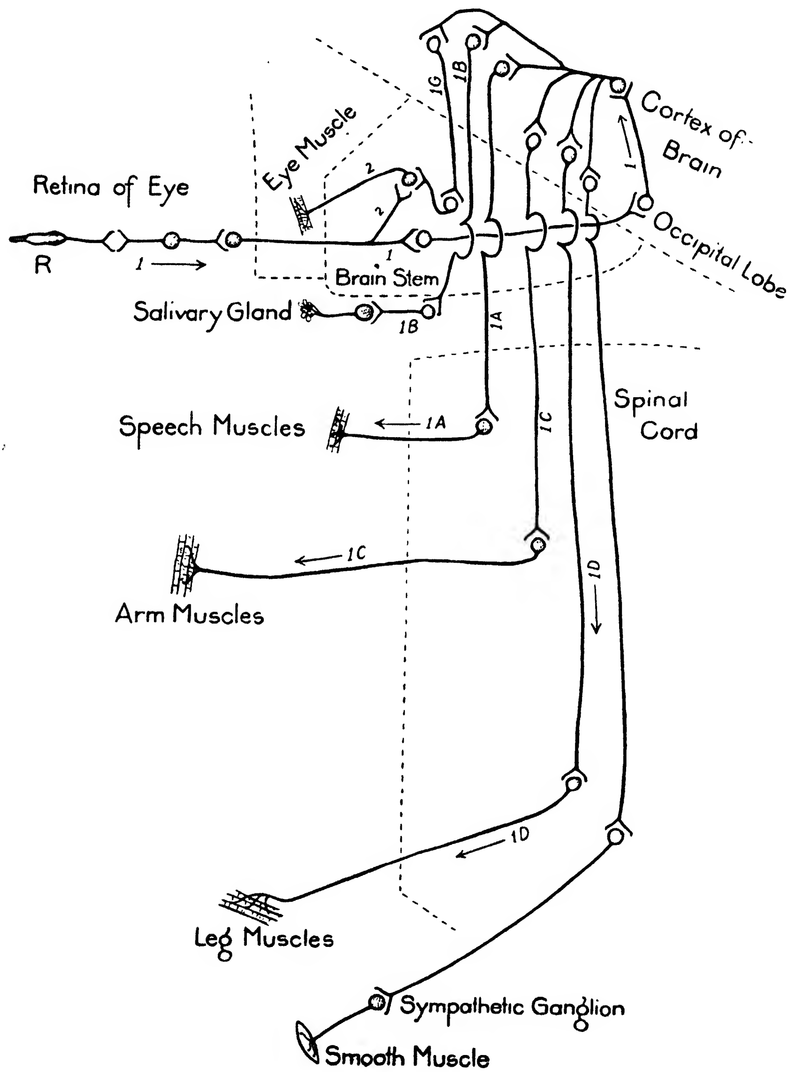

Fig. 12.—Scheme of reaction pathways commencing in retinal receptors (R), indicating the possibilities of connection between these receptors and various effector systems.

ganglionic cells. Through this arrangement, an axon issuing from the brain stem or cord distributes its stimulus to a larger number of effectors than would be possible otherwise. The arrange-

is satisfactory for these effectors which may react uniformly in groups, but would not be satisfactory for skeletal muscles, where nice discriminations in reaction are necessary.

The functioning of afferent and efferent neurons is relatively simple. Current due to stimulation of a given receptor can enter the cord or the brain stem at only one point. Current emerging

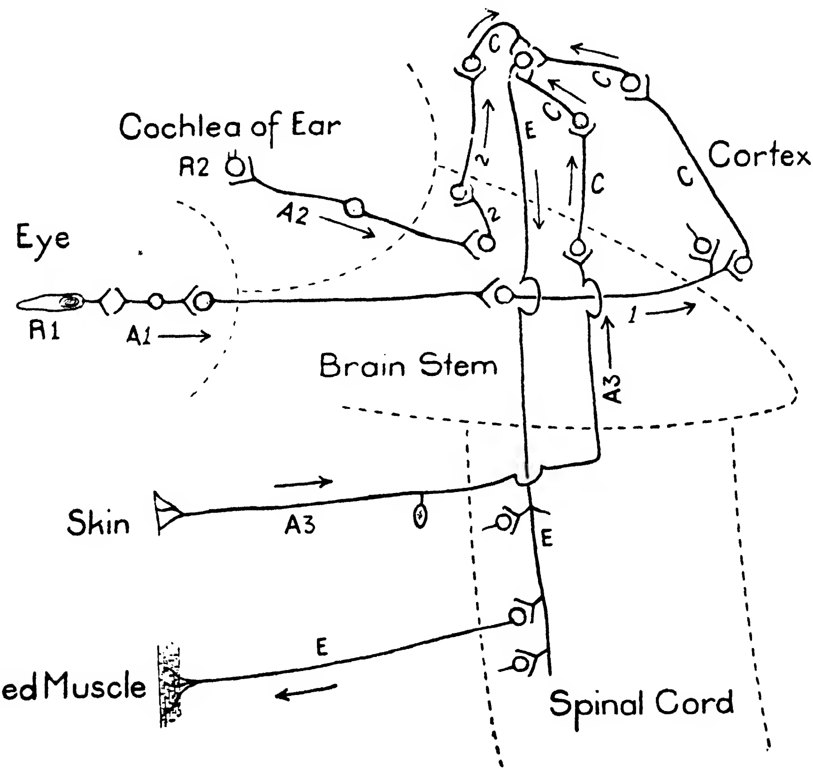

Fig. 13.—Scheme of reaction pathways terminating in muscles producing finger movement.

from the cord or brain stem at a given point can go to only one effector or effector group. The central neurons, however, provide a multiple switching system, by which an afferent route can be connected with any one of several efferent routes. If we consider the cord, brain stem and hemispheres together, they may be compared to the exchange of a telephone system, through which any calling phone can be connected with any other phone. The

difference is that the "sending" (receptors) and "receiving" (effectors) stations in the nervous system are distinct; whereas they are combined in the telephone system. The nervous system is a "one-way system." But within this system a given receptor can be connected with almost any effector, or with several at the same time; and conversely, a given effector may have connected to it any one of a wide range of receptors or various combinations of receptors.

The multiple possibilities in the way of interconnection of receptors and effectors are provided by the many-branched axons and dendrites of the central neurons. If we assume that the first axon entering a cerebral hemisphere has branches in contact with only ten neurons: and that each of these ten have axon branches in contact with ten other cells, and so on, a succession of five cells between the entry to and the exit from the hemisphere would mean a choice of 100,000 routes. No idea of the exact number of possibilities can be obtained, but we may be assured that it is so great that practically any receptor can transmit current to practically any effector.

The possibilities in the way of switching through the cord and brain stem alone are more limited. Only a few efferent routes may be connected with any given afferent route, and *vice versa.* As for the functions of the cerebellum, little can be said, although we know that it adds greatly to the efficiency of the total switchboard system, even if it does not add to its variety. The importance of the hemispheres for the mental life is solely in the interconnecting system they provide.

Sensory and Motor Cortex

The cortex, or outer part of the cerebrum, in which lie chiefly the cerebral neurons, is divided conventionally into *sensory* and *motor* areas, and the neurons whose cell bodies lie in these areas are described as "sensory" and "motor" cells. The sensory areas are the areas to which the afferent current is sent directly from the spinal cord and brain stem, and from which it is directed to other parts of the cortex. The motor areas are the areas from which current from the cortex is sent to the efferent neurons which lead out from the cord or brain stem to the effectors. Current

which passes through the cerebrum must enter it at one of the sense areas, and leave it again from some point in the motor area. Each of the senses is believed to have its particular sensory area or "sensory center" in the cortex, and every part of the effector system of the body has its definitely localized cortical motor area or "motor center." The sensory centers for vision, hearing, smell and taste have been located, and the centers for the dermal, somatic and visceral senses seem to be identical with, or close to, the motor centers for the same parts of the organism.

§6. Heredity.

The animal which develops from the original fertilized egg possesses characteristics which were largely determined in the egg. These characteristics are not merely of structure, but include functional tendencies also. The animal will tend to act in ways determined by its heredity, and its heredity is all "carried" somehow in the fertilized egg.

It is known that the chromatin in the nucleus is the chief, if not the only "carrier" of heredity. Part of the chromatin in the fertilized egg came from the female germ cell which produced the egg; the other part came from the male germ cell, when the nucleus of the sperm cell penetrated the egg and joined the egg nucleus. In the division of the egg into two cells, the combined chromatin, which contains the characteristics of the new animal which will develop from it, breaks up into *chromosomes:* and the behavior of these chromosomes in mitotic cell division is an intricate and fascinating process.

It will be noticed that we do not say that half of the chromatin in the fertilized egg is derived from each parent *animal;* but we say that it is derived from the parent germ cell. This distinction is important. Neither the spermatozoon nor the egg cell is produced by the organism within which it develops. Take the case of the male parent, for example. When his body was developed, certain cells, progeny of an original fertilized egg, remained in an undifferentiated state, being germ cells, precisely like the original egg; while the other cells developed into the body. The testicles developed about these germ cells, and they continue living in the testicles, producing other germ cells like themselves and

also producing spermatozoa, which are "reduced" germ cells. But these germ cells, although living within the body of the animal, and deriving nourishment from it, were not *produced* by it, but are merely collateral descendants from the same parent-cell. They are parasitic on the organism, drawing food from it, and depending upon it to introduce the spermatozoa to the vicinity of egg cells, that they may fertilize them and so continue the breed of germ cells, and incidentally, of animals. Practically, the only effect the animal body can have on the normal course of events affecting the germ cells living in its own testes or ovaries is to starve them, or to refuse to introduce sperm cells to the vicinity of eggs, or the converse. The germ cells are descendants of an indefinitely long line of germ cells, modified by many cross matings of egg with sperm cell; and the bodies in which these germ cells have lived, and which have assisted them in their matings, have been by-products, which have literally had no progeny.

It is obvious, therefore, that education or training of the parents has little or no effect upon the children, but only upon the parents; and that improvement in the character of human beings, whether physical, mental or moral, is possible mainly through selection of the stock having the best heredity, *i. e.*, the germ cells which will produce the best human animals. Such improvements are passed on to succeeding generations, whereas the improvements made by education affect primarily only the persons who are educated and not their children.

§7. Reactions and reaction arcs.

When a sufficient stimulus is applied to a group of receptors, we have the process, beginning in the receptors and ending in effectors, which we call *reaction*. Although it is practically impossible to stimulate a single receptor, we may for the moment consider the reaction process as it would occur if a single receptor were stimulated, and will assume the receptor to be in the retina. The receptor (rod cell or cone cell) irritates the next neuron (small bipolar), this in turn irritates the third (large bipolar), through the axon of which a cell body lying in the brain stem is irritated. This in turn has an axon extending to the occipital lobe of the cerebral cortex, where it irritates a fifth cell, a branch of whose

axon may extend to the frontal lobe. From there, an axon branch extends to the motor area of the cortex. There it irritates a seventh neuron, whose axon extends downward into the spinal cord, where the final neuron, whose axon extends to the muscle fiber in the arm, is stimulated, and ends the process by stimulating the muscle fibers.

This whole process is *reaction.* The contraction of the muscle-cells is *action.* The neural discharge from the receptor to effector is the *neural transit.*[94] The chain of neurons over which the transit takes place is the *reaction-pathway* or *reaction arc.*

We must understand that no such simple reaction ever occurs. Actually, several, or a great many, receptors of the same sense are stimulated, and afferent current is sent over a number of parallel routes. Furthermore, the arcs branch in the centers, and the resultant reaction involves a great many effectors in various parts of the body. Finally, the efferent current directed to a certain group of effectors is not derived exclusively from a single afferent source, but from a wide range of sources, combined in the centers. In the reaction of the finger movement to a retinal stimulation, for example, the stimulus produces, or helps to produce, changes in muscles and glands all over the body; and stimuli to receptors in ears, skin, muscles and viscera assist, or modify the finger-reaction.

Yet, since we may consider a single-file reaction arc as a legitimate representation of a number of parallel routes: and since in any given reaction, however complex, there is usually a principal afferent branch, and a principal efferent branch, the concept of the reaction arc is both permissible and useful.

All reactions are primarily adjustments of the organism, and hence necessarily eventuate in muscular activity, or glandular action, or both. Stimuli of various kinds produce reactions which provide for the various needs of the animal: reactions of defense, of flight, of seeking food, rest, and water, or sexual intercourse. All of the activities in which these reactions terminate involve glandular secretion as well as muscular contraction. The food reaction, for example, involves secretion of the salivary glands,

[94]The term *neural transit* is new, and introduced here because there is no equivalent term in use.

and of glands in the stomach, intestines, liver and pancreas. And all of these actions are brought about by a wide and complicated range of stimuli. The food reaction, for example, is initiated by the sight, smell and sounds of edible objects, and by the internal stimulus of hunger. In addition to these primary reaction groups, various minor reactions, such as those involved in brushing away insects; and multitudes of non-essential reactions, such as those of play, develop.

Eventually, some types of reaction become reduced to the point where the actual muscular and glandular activities are slight, and perhaps negligible. You hear the chimes ringing the hour; afferent current is started from the cochlear hair cells, but the efferent result is not easily demonstrable. A man walks across the road in front of you, and your retinal receptors respond; but no overt action on your part follows. In some cases, the reaction is a diffuse one, affecting slightly the whole organism; in others, there is activity of the muscles of speech. Perhaps in all cases of sensory stimulation there really is complete reaction. It may be that in some cases the efferent part of the reaction is short-circuited, and the action prevented. But however that may be, these incomplete reactions are of the very highest importance for our mental lives, as will be shown later. For the present, we shall deal with reactions which are complete, eventuating in demonstrable activities. The incomplete reactions follow the same general laws as the complete reactions.

The reactions of which a human being is capable are of almost infinite variety. Considering the muscular reactions alone, we find that thousands of muscle fibers participate in the simplest movements of the fingers. These fibers contract and relax in a definite time order, and a change in this time-order, or a change in the particular fibers contracting, makes the reaction a different one. The ultimate effects of slight variations in reactions may be great. In writing, for example, a vast number of different finger and hand movements are possible, and the significance of writing *e* instead of *i*—a very slight change in the action pattern—may be enormous.

The specific muscle fibers involved in a reaction, and their specific time order of contraction and relaxation may be desig-

nated the *action pattern.* The action pattern in any reaction will depend upon the specific neural discharges to the muscle fibers, and the time order of these; and so we may speak also of the *neural pattern* of a reaction. The *neural pattern,* in turn, depends in part upon the general synaptic conditions in the brain and spinal cord, as will be described under the topic of habit formation: and in a given synaptic condition, it depends upon the *stimulation pattern,* or *stimulus pattern* applied to the receptors.

We must take the stimulus pattern into account at this point, because reactions do not occur merely to the application of energy, where none was previously applied; but may be brought about also by the removal of stimulation, or by *change* in the total stimulation applied at any time. In short, the *stimulus pattern* is the important factor at all times, so far as the initiation of reaction is concerned.

For example: you are watching a gray spot dimly visible through the underbrush; it moves, and you raise your gun; it is game, and not a stump. The slight movement made no significant increase in stimulus to the eye, but the *pattern* changed: the distribution of stimuli on the retina changed, and a definite reaction resulted. Strictly speaking, there was reaction going on all the time, but as the stimulus pattern changed, the whole reaction pattern (neural and muscular-glandular patterns) changed suddenly.

The vital significance of the reaction pattern will become apparent when we have discussed the integrative action of the nervous system.

§8. Types of reaction.

The five important types of human reaction are: (1) Reflexes, (2) Perceptual reactions, (3) Ideational reactions, (4) Volitional reactions, (5) Automatic reactions. Reactions of the first class are unconscious: those of the second, third and fourth classes are conscious: those of the fifth class are less conscious, approaching the unconscious type; and perhaps actually unconscious in extreme cases.

(1) *Reflexes,* sometimes called "physiological reflexes," are reactions such as the "wink" of the eyelids which follows the entrance of a grain of sand into the eye, or follows the sudden

approach of an object to the eye; the "knee jerk" which follows a stroke on the patellar tendon just below the knee cap; the narrowing of the pupil of the eye (pupillary reflex) when a strong light is flashed into the eye; and the general "start" of the whole body when sudden and unexpected noise occurs.

These reflexes have two characteristics which are important. *First,* they are brief in duration, consisting in general of a single contraction or relaxation of a muscle or of the members of a group of muscles. *Second,* they are relatively invariable, a particular stimulus always, in the normal subject, producing the particular reaction. If the reaction (such as the knee jerk or the pupillary reflex) does not follow the appropriate stimulus (the blow on the tendon or the flash of light), this failure is evidence of an abnormal condition of the patient. In many cases the invariability extends to the stimulus, one specific stimulus, and one only being capable of producing the reflex.

Reflexes of smooth muscles and glands also occur. The saliva starts to flow when the odor of lemon juice assails the nostrils. The muscles attached to the hair bulbs contract under the stimulus of cold, producing "goose flesh;" the muscular coats of the blood vessels contract or dilate under various stimuli, this action in the vessels of the skin being apparent as "paling" and "blushing." Probably all of the glands of the body are subject to reflex action of this kind.

These reflexes take place probably through the cord or the brain stem alone. The afferent current, in the case of the knee jerk, is conveyed by the afferent neurons to the cord through the third and fourth lumbar roots; is transferred across the cord to a motor neuron whose cell body lies in the cord; and over the axon of this neuron the motor current runs out to the extensor muscle of the thigh. The arc involves certainly not more than four, probably three neurons (one afferent, one efferent and one central), and possible only two. The *pupillary* reflex involves an afferent current carried to the optic thalamus by a chain of three neurons, and from there back to the iris by a single efferent neuron. In other cases the reflex arc may enter the brain stem and from there run out through the cord, or *vice versa; but it is possible also* that all such reactions belong in the next higher group.

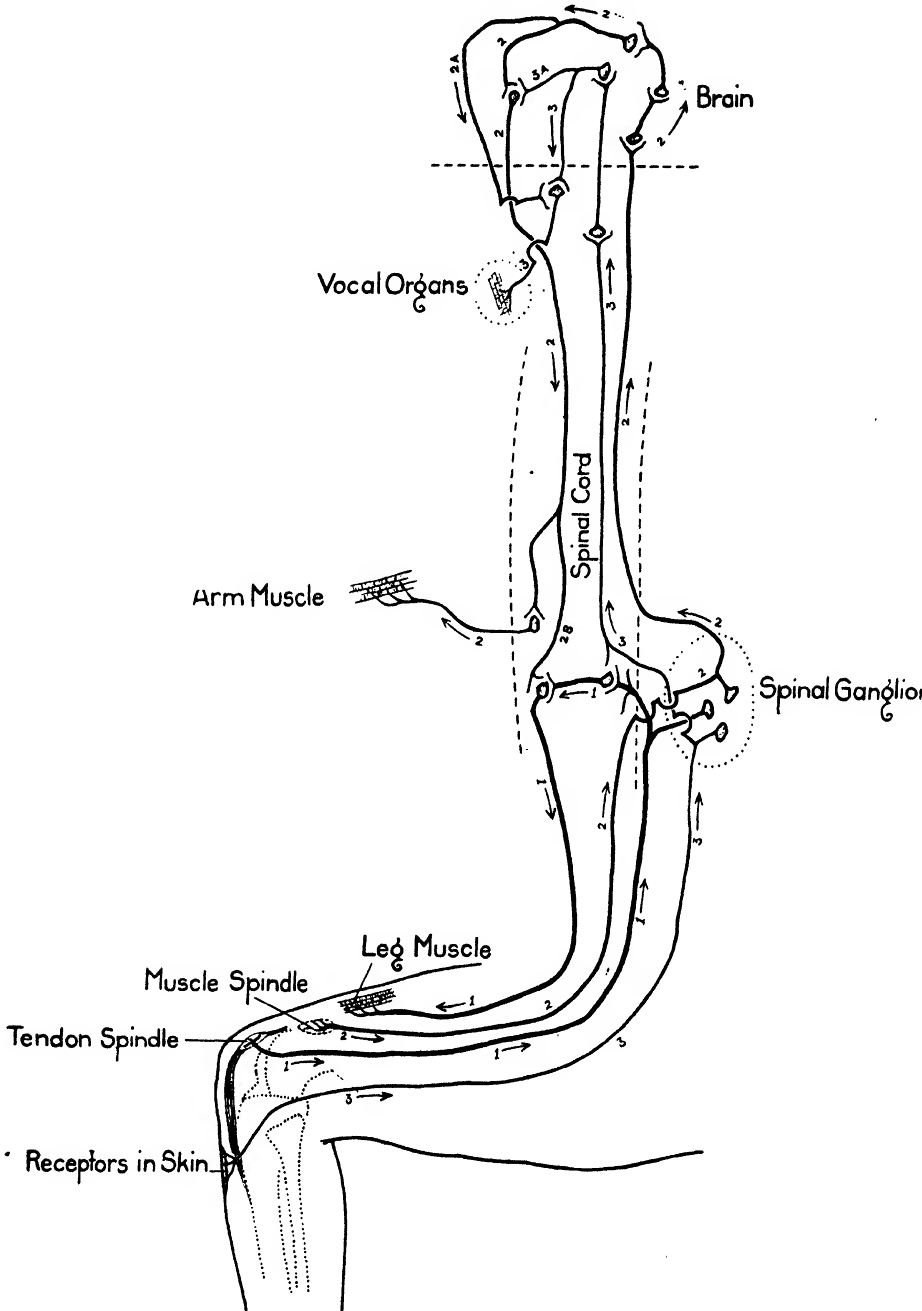

Fig. 14.—Scheme of pathways involved in the knee-jerk, and in the accompanying perceptual reactions. 1 is the arc over which the reflex occurs: 2 is an arc over which occurs the reaction of perceiving the movement: 3 is an arc over which may occur the reaction of perceiving the blow (stimulus).

In the reflex, no consciousness is involved in the essential transit. It is true that in the case of the knee jerk, the patient is usually aware of the blow on the tendon, and of the resultant "kick," but these awarenesses are not essentially connected with the transit which actually terminates in the action. These perceptions are due to transits over other arcs passing through the cerebral hemispheres, and the kick occurs just as perfectly if these transits and their associated consciousnesses are absent. In lower animals, as for example in the cat, the knee jerk persists after the spinal cord has been severed in the cervical region; in man, severing the cord in this region temporarily abolishes the knee jerk by destroying the tonicity of the muscles; but in every case it destroys consciousness both of any stimulation of the leg, and consciousness of movement of the leg: and in many cases, the knee jerk will in time be restored, without consciousness.

(2) *Peceptual reactions.* There is a large class of reactions differing from the above described reflexes in that perceptual consciousness, the perception of some object, is essentially bound up with the reaction, forming an integral part of the total process. In this class are such reactions as the catching of a ball, pouring water into a glass, taking the change the conductor hands you, picking up a card from the table, and an endless number of similar performances concerning which it is sometimes wrongly supposed that the action follows the perception of the object, but in which, as a matter of fact, the perception is dependent on the reaction rather than *vice versa.*

Certain of these reactions, originally perceptual, may in the course of time come to be done without the perceptual factor (see below), and in general, the vividness of perceptual consciousness involved in these reactions varies from high attention to very low vividness. The reduction of actions from the conscious level to, or towards, the non-conscious level, is a normal and essential feature of increasing efficiency of conduct, and is one of the definite purposes of education.

Among perceptual reactions are some that we call *imitative,* in which the consciousness involved is the perception of an action performed by some one else; and the reaction with which the perception is united, is the production of the same, or somewhat the

same, action by the reacting individual. These are imitative reactions in the strict sense; but the term imitation has been extended far beyond the field of perceptual reactions, and is frequently applied to complex processes involving ideation as well as perception.

(3) *Ideational reactions.* In some cases a reaction, whether or not accompanied by perceptual consciousness, involves *thinking.* I turn around to look at the clock as I remember an engagement. I open the book on my desk when I think there is a paragraph in it I wish to read. I get up and walk into the next room when I recall that I left the light burning there. In these cases, the thought (imagining, remembering, etc.) seems essentially involved with the reactions.

Under the head of ideational reaction comes the so-called "influence of suggestion," where, under hypnosis or in normal conditions, actions are "suggested" to the reactor by another individual. In these cases, as in all ideational reaction, the action does not follow the idea: but the two occur together, as parts of a total process.

The idea with which the action is functionally connected—with which it makes up a total psychobiological process—may be the idea of the action itself. But such is not necessarily the case. My idea, in the process of striking a nail with a hammer, may be the idea of striking; but more often it is the idea of the nail going into the wood. In stretching out my hand to the table, my idea may be the idea of stretching out my hand; but it is more often the idea of something on the table. Apparently one and the same reaction may at different times be bound up with different ideas; but this appearance is probably fallacious. The reactions may be alike in their more obvious results, but nevertheless differ in their details. It must be noted, moreover, that the movements of the limbs and trunk muscles are not the whole action, either in the perceptual or the ideational cases; but that the whole organism is apt to be affected.

In the repetition of ideational reactions, perhaps more emphatically than in the case of perceptual, the tendency for a primarily conscious reaction to become non-conscious, or nearly so, is in evidence. I push the switch button when the daylight grows dim,

not with the thought of the light I am to have, but because I have formed the habit of pushing it when the room becomes obscure. The thought-element in this reaction, which was present in the formation of the habit, has disappeared, leaving the reaction, in so far as the consciousness is concerned, on the perceptual level. In other cases, which cannot be taken into consideration until we have discussed the association of ideas, the conscious element seems to evaporate entirely from the reaction, and this is in general a very useful tendency.

(4) *Volitional reactions.* In many cases, the ideational reaction involves the consciousness of desire,[95] assent or selection, which gives it the character we designate as volitional or voluntary, the character of *will.* There is in these cases an *anticipatory idea;* an idea of something which at the time is not in existence; and there is the desire of its realization. The desire involved in volitional reaction may be the desire of the act in which the reaction terminates; or it may be desire of some object which the act secures; or of some situation which the act brings about. I may, for example, will to clench my fist, or will to open my mouth; or I may will that the curtain be raised, or that the lamp be brought nearer to me.

Although desire is the characteristic feature of will, there may be desire without will, but there is no sharp dividing line between the two cases. In many cases, the desire for a certain condition is united with an act which is directly relevant to the bringing about of that condition. My desire for cooling off, for example, may occur with the act of getting out of my chair to go outside, the desire and the act forming then a single voluntary reaction. My desire to avoid meeting a disagreeable person may be united with the action of turning to go down another street.

In other cases, the desire occurs some time before the practically important act. For example, I desire a drink of water, and decide to obtain it after finishing this page. There the primary

[95]Aversion may take the place of desire in an act of will: aversion either to an object or to a situation. It is to be understood that in the general statements concerning will, aversion is to be substituted for desire to make the statement valid for the alternative cases. One may act on a desire for the result, or on an aversion to the situation which would result from not acting: for instance: one may search for water with a desire for the liquid, or a desire to drink; or with an aversion to thirst, or an aversion to being unprovided with water.

desire, as it first occurs, is not a part of the total reaction which includes starting for the drink, although some consciousness is involved in that reaction; and the desire may, in fact, recur as a part of it. A new factor, *decision,* is also introduced in these cases.

As a matter of fact, the first desire in such cases is united with an action—is a part of a reaction which has a definite causal relation to the later action in which the volition is "completed," and the occurrence of this first reaction is the *decision.* Decision, then, marks the completion of the real volition, and the final action is either a mere ideational or perceptual reaction dependent upon the preceding volition, or else, if the desire recurs with this final action, it is a new volition resulting from the first.

The first volitional act, in the case we have just been considering, where the completion of the volition is delayed, is an act of some kind which will bring about the final act through the process of association (which is to be considered later), without necessitating the further operation of desire. This decision may not be attained in the first reaction in which the desire occurs, but may be the result of a series of ideas (that is to say, as we shall show later, a series of ideational reactions), through which the desire persists. This is the process of *deliberation,* in the course of which there is usually the occurrence of conflicting desires, *i. e,* desires of conditions whose realizations would be conflicting.

Deliberation may occur in cases where there is not decision; where therefore the act in the final volitional reaction is an act directly related to the bringing about of the desired condition. For example, I may deliberate whether or not I shall post a letter I have written, which commits me to an important step, while I hold the letter in my hand; then, I may drop it in the box with conscious desire to do so (or with desire to commit myself to the course). In such a case, there is no decision; no settling of what is to be done before it is done: what is to be done is settled in the doing of it. On the other hand, the deliberation might be finished, the decision made (to post or not to post the letter), before I come to the post box, and no outward alteration of my

conduct effected until the moment when I have either to pass on or turn towards the box.

The consciousness of the desire in volition varies in degree. The intensity of the desire present also varies, doubtless in a continuous way, down to the zero point; so that there is no sharp line of division between the mere ideational reaction and the voluntary reaction. The whole matter of the causal efficiency of desire is obscure, and we can by no means be certain that an increased degree of consciousness of a desire increases the probability that it will eventuate in a will-act, or that the reverse is true. Desires, we must remember, are actually bodily conditions, and must influence our actions whether we are conscious of them or not. How their influence is modified by their coming into consciousness, we cannot say.

Consent and *assent* are very probably weaker forms of desire, but our present knowledge of the details of conative content and conation does not permit us to form a conclusion on this matter.

(5) *Automatic reactions.* There is a tendency to eliminate the distinctly volitional factor in reactions several times repeated; an elimination which, if it were not further modified, would reduce the reactions from the volitional to the ideational type. There is, however, the tendency which we have indicated earlier, to reduce the ideational reactions to the perceptual level, or to the unconscious level, by the elimination of the idea from reactions which were in their earlier occurrences vividly conscious. The reactions involved in rendering a written score on the piano are at first voluntary; then, as proficiency increases, they become largely perceptual. The successive movements in buttoning up a garment are probably for a child not merely ideational, but volitional; but for us adults the volitional characteristic is almost always absent, and the ideational factor is reduced to a preliminary idea of the process as a whole,—if any idea at all is left. The perceptual character of the several steps in the series may remain, but frequently the whole process will be carried through with only occasional perceptions of the details involved.

The elimination of consciousness from reactions which were originally perceptual may be strikingly illustrated from the various reactions involved in a series of regularly repeated movements,

such as the waltz. For the learner, the taking of the successive waltz positions is vividly conscious: the completion of one movement of the legs is the consciously perceived stimulation for the reaction which brings the legs into the next position. With practice this consciousness disappears, and the leg movements follow each other like simple reflexes, consciousness being free to take account of the general direction of the progress down the room, the avoidance of obstacles, and the various contents due to the partner.

These reduced reactions, which were originally highly conscious, and from which the conscious factor has been eliminated to a large extent, are called *automatic reactions*. The class of automatic reactions is, however, a large and varied one, ranging from the type in which ideational reactions have been reduced to the perceptual level with only occasional ideational movements, down to the type from which all consciousness, ideational and perceptual, has been eliminated completely—a type seldom realized. Although in the general manner of its occurrence this extreme or "pure" automatic action somewhat resembles reflex action, it is not to be confused with the latter. That the neural conditions of "pure" automatic action are different from those of reflex action is indicated clearly by the fact that the former may revert at any moment to the conscious type.

Consciousness is important for the learning process: that is to say, for the modification of reactions, or the prevention of modification in reactions which have not yet become fixed; but the very purpose of the learning process is to automatize, and make mechanical, the reactions which have reached a satisfactory stage of development, and by the elimination of consciousness, or its reduction to a minimal level, prevent further modification of these reactions. It is desirable to automatize as much of our reactivity as possible, leaving the conscious field free to accommodate the reactions which must be modified, and to direct in a general way the series of automatic reactions, starting, stopping, or modifying these series as circumstances demand. In general, it is better to automatize too much than too little: the individual who makes the details of petty and familiar action a matter for needless attention is both emotionally psychopathic and practically inefficient.

§9. Local and spontaneous activities.

Analytically we may distinguish from the true reactions initiated by stimulation of receptors, two other forms of activity, in one of which, *spontaneous activity,* receptors are not involved, and in the second of which, *local activity,* no neural action is involved. Actually, these two types of activity seldom occur unmodified in the human organism; the tendencies to produce them being so modified by concurrent reaction tendencies that the result is a combination ranging from local activity modified by reaction to reaction modified by local activity.

Local activities are actions of muscle and gland cells not dependent on stimulation of these cells by neurons, but brought about by chemical processes in the effectors themselves. The beating of the heart (rhythmic contraction of heart muscle) and the secretion of urine by the kidneys are types of local activities. Although these are normally modified by neural discharge, they can go on when the nerve connections with these organs are completely severed. As these processes normally occur, therefore, they are to be considered as local activities "controlled" (*i. e.*, accelerated or retarded) by neural transits. Local activity seems to be a property of smooth muscle, cardiac muscle and gland cells, not of striped muscles in their normal condition.

Spontaneous activities are activities of effectors stimulated by efferent discharges originating in motor nerve cells, without the stimulation of these nerve cells by other nerve cells. The breathing process is perhaps a type of this spontaneous activity, or would be, if we could prevent reaction processes from modifying it, as they constantly do. Motor cells in the medulla, it is believed, tend to discharge rhythmically to the breathing muscles, producing respiration at a fixed mechanical rate. Such breathing would, of course, be inefficient, since the rate of breathing must respond to the oxygen needs of the body, and although based upon a spontaneous tendency, respiration, under normal conditions, is largely controlled by reactions.

§10. Mixed reactions.

We have seen that pure local activity of muscles and glands does not occur in normal life. If the control by the nervous sys-

tem were removed, certain muscles and glands might show purely local activity, for a time, if other circumstances were favorable. The same general considerations apply also to reflex activity. There is much more reflex action in the behavior of man and the higher vertebrates than appears to casual study. If the cerebral hemispheres are removed, and the perceptual components of these reflexes removed, they can be evoked as pure reflexes, occurring in a machine-like way. The alternate movements of the legs, in walking, are partly reflex, partly perceptual: that is, in the complex arc involved in one of the leg movements, one set of neural pathways leads through the cord and brain stem alone, and another set leads through the cerebrum as well as through the lower structures. Through this branch of the total arc, the reaction is subject to integration with, and hence control by, the general bodily reactions. Local stimulation of the foot will not produce a walking movement, unless proper stimuli have been applied to other sense organs, as in seeing the ground: or else the *idea* of walking is present. If, however, the loop in the route, which passes through the cerebrum, is removed, the more direct connections through the cord and brain stem function without interference, and by stimulating the bottom of the foot in a way similar to that in which pressure on the ground affects it, the *walking reflex* can be obtained, regardless of general conditions of stimulation.

§11. Reactions of the glands and smooth muscles.

All glands, including the ductless or "endocrine" glands (such as the thyroid, adrenal, and pituitary) as well as the duct glands (salivary glands, sweat glands, liver, kidneys, etc.) are supplied with efferent nerve fibers through the "autonomic" division of the nervous system. Some of these fibers end in contact with the secreting cells of the glands. Others end on the smooth muscle fibers of the blood vessels of the glands. In the case of a duct-gland, the ducts, through which the secretion of the gland is discharged, have layers of muscular fibers, which are supplied with efferent nerve fibers.

The effects of nerve currents on the gland as a whole are therefore of three sorts:

1. The secreting cells may be directly stirred to greater activity, or their activity may be inhibited.

2. The blood vessels in the gland may be dilated or constricted, thus facilitating or hindering the activity of the secreting cells by increasing or decreasing the supply of materials from which the cells manufacture the secretions.

3. The duct of a duct gland may be dilated or constricted. By dilation, secretion may be allowed to accumulate in the duct, and later squeezed out by contraction.

If a cut lemon is brought under your nose, there will probably be an immediate increase in saliva in the mouth due to the contraction of the salivary ducts, and a further increase due to the stimulation of the gland cells, and the increased blood supply due to dilation of the capillaries. The same effects may be due to the mere sight of a lemon, and will almost always be produced by the sight of some one sucking a lemon. Thought of a lemon, if the content includes either the taste or the smell of the juice, will produce the same result: you may notice a salivary flow as a result of reading the above statements. The thyroid gland shows in a striking way the increased blood supply due to certain forms of stimulation (as in fear and rage), sometimes by its visible swelling, sometimes by the "choking" feeling of its pressure on the wind-pipe.

All reactions whatever probably involve some glandular effects. By use of the so-called "psychogalvanometer" it is easy to demonstrate that various perceptual and ideational processes, especially those which are emotional, involve changes in the secretions of the sweat-glands.

Activities of smooth muscle elsewhere than in the glands are easily noticed. "Goose flesh" is due to the contraction of the *levatores papilli* muscles which pull outwards the hair follicles. The smooth muscular coats of the arteries everywhere are constantly being contracted or relaxed, modifying the blood supply of the various organs. These vascular changes may be demonstrated by blood-pressure measurements and are seen as blushing and blanching of the skin under various conditions of thought and perception.

The muscles and glands of the alimentary and urinary systems

although controlled largely by the local nervous system, are played upon by all the variations in activity of the central nervous system. The effects of the appearance, smell and taste of food, and the effects of worry and happiness, upon the digestive processes, are well known. Fear may involve increased secretion of fluid in the large intestine, with relaxation of the anal sphincter. Prolonged mental labor may induce constipation. Sudden laughter in the female sometimes is accompanied by relaxation of the sphincter of the bladder. The heart muscles, although contracting automatically, are continually stimulated and inhibited by efferent nervous currents, which are dependent upon the total integration of the afferent currents from various parts of the organism, so that the heart action responds to the needs of the whole body. Extreme instances of this nervous control are often noticed in the sudden quickening or checking of the heart beat, not only consequent on sensory stimulations under certain conditions, but also as an end-result of certain ideational cases. The sudden anticipation of a pleasurable occurrence, usually quickens the heart beat, and the sudden thought of danger to yourself or others usually involves checking, at least momentarily, of the heart action.

The mechanism of sexual excitement is one of the most complicated of the bodily systems. Glandular secretion and vascular dilation are produced by efferent current from the central nervous system, along with contributory activities of striped muscles as parts of combined perceptual and ideational reflexes. These effects are not merely local, but involve the glands and muscles of the entire organism in definite and recognizable ways. The results of the general excitement stimulate the purely mechanical reflex in which it normally terminates. The reflex may, under some circumstances, occur with little effect upon the organism in general: but the excitement of sex interest, even in the common social ways, is never without local effects.

It is because of the profound and general effect of sexual perceptions and ideas that the lavish stimulation due to the theater, movies, erotic stories and more direct circumstances which form so large a part of civilized social life, is unwholesome. Dancing, which has been under the ban at times on account of its supposed erotic effects, does not increase these effects on the whole, but rather dissipates them.

CHAPTER X

REACTION AND CONSCIOUSNESS

§1. Degrees of consciousness.

One of the striking things about consciousness is that it may vary in degree: I may be *more or less* conscious of any given content, without any change in the content itself. As I sit here at the present moment, I am conscious of the whirring of the electric fan in the next room. This whir is a constant sound, which affects my auditory receptors continuously. Its intensity, pitch and timber do not change to an appreciable extent. Yet, at one moment, I am "vividly" conscious of it: or I might say, it is a "vivid" sound. At another moment, I am conscious of it much less vividly: it becomes a part of the "background" of content. Yet the stimulation of my auditory receptors is the same at both moments.

Another way of expressing these facts is to say that I am *more attentive* to the noise at one moment than at another. *Attention* and *consciousness*, in fact, are terms which are to a large extent synonymous: attention is, however, used most generally to designate the higher degrees of consciousness. When I am "attentive" to any content, I am highly (in degree) conscious of that content. When I say that I am "inattentive," I mean that the degree of consciousness is low. We speak of attentive consciousness as vivid consciousness; and we say also that the content is vivid, meaning that we are vividly conscious of it.

Although we cannot say strictly that consciousness is complex, or composite (although its *conditions* are highly complex), yet we do find that at a given moment we are vividly conscious of one detail of content, and less vividly conscious of other details. I may be conscious of the noise of the fan, and of some one's voice, at the same time; vividly conscious of one, and much less vividly conscious of the other. I may be conscious of auditory, visual and olfactory objects at the same time that I am conscious

of my body, viscerally and kinesthetically, and the different factors in the total content may have different degrees of vividness. In such a case, the details of content which are most vivid are said to be "focal," or "at the focus of consciousness," while the least vivid are said to be in the margin of consciousness, or "marginal."

It is seldom that the same content, or detail of content, remains "focal" for long. The "focus" is constantly shifting, attention being now to this detail, now to that. Even in cases of continuous attention to one object, the attention is apparently in a series of pulses, each of brief duration. Apparently each "act" of consciousness is a matter of a few seconds, and attention to a single object must be repeated, if it is to be continued. Attention to a series of objects is, therefore, easier than attention to a single object, if it is to be long continued. The duration of attention, in any single act of consciousness, is, under usual conditions, less than a second, but may be extended to several seconds.

The question is frequently raised as to the scope of attention: as to how many things can be "attended to" at one and the same time. Attempts have been made to settle this question by determining how many separate objects (words, letters, pictures, etc.), presented to vision simultaneously for a fraction of a second, can be *remembered* immediately afterwards. Of such objects, six may be remembered by the average person, when the exposure has been just long enough for clear vision, and the objects are all familiar, and are presented to central vision. Some individuals can note and remember but three; others may remember more than six. If the objects are related to each other in definitely perceptible ways, still more can be remembered. Any number of details so related as to form a composite whole may be remembered as a single object.

§2. Integration.

Consciousness is *integrative:* that is, it tends, in any act of being conscious, to be awareness of total situations, rather than of unrelated details. A certain presentation of various forms and colors is seen as a *single* landscape; a certain varied collection of sounds is heard as an orchestral strain; several persons are per-

ceived as a group. Several sounds in brief succession are usually perceived as more than a series: they may constitute a rhythmic group, or a musical phrase. The uniform tendency of both perception and thought is towards unitary awareness of a complex object. This synthetic, or integrative aspect of consciousness is of far-reaching importance. When we have integrated objects in this way, they acquire definite relationships which determine our future thought and future perception. This characteristic of consciousness has its foundation in the integrative action of the nervous system, and is the key to the relation between nerve action and consciousness.

The integrative aspect of neural function is the tendency of the various reaction arcs passing through the nervous system at a given moment to be welded into a single complex arc, with many afferent and many efferent branches. Because of the multiple synapses of neurons in the brain, there are routes through which any arc may establish connections with any other arc; and the fundamental tendency of the nervous system is to establish such connections. In other words, aside from certain limited reflexes, the nervous system tends to act as a whole: to integrate.

The player catching a ball, for example, reacts principally by arm and head movements, to a visual stimulus. But he reacts also with the muscles of the trunk and legs, all of which are brought into play. In addition, the smooth muscles of the arteries, and even of the alimentary canal, are affected, and changes in the tensions of these muscles may be demonstrated in many cases. It is probable that the glands throughout the organism: digestive, urinary, sudorific and ductless: are involved, although the glandular part of the reaction may not be important in this particular case. All these details in the total reaction are not results of the single stimulus of the approaching ball. Other visual stimuli, such as those of the runner between bases, and the basemen, are highly important. The player will not catch in practice in exactly the same way as in a close game. The auditory stimuli; the yells of the other players, and of the crowd: are stimuli which may materially alter the reaction. All these stimuli contribute to a single reaction, involving practically the entire organism, the various component transits of the reaction being integrated in the

brain and brain stem. In this total reaction, however, there is one dominant transit; namely, the transit from retinal receptors to arm muscles; and although the player is really conscious of the various visual and auditory contents mentioned above, and of many other objects, including his own body, the *ball* is at the focus of consciousness. The player is, for the moment, attentive to, or principally conscious of, the ball. The next moment, his attention may be turned to the runner, or to a baseman; but this requires a second reaction, following the first one. Perceptual attention, then, or a high degree of perceptual consciousness of a given object, depends upon an integration of the nervous system, in which the arc initiated by the stimulus corresponding to the object is dominant. From this point, the step to the discovery of the physiological conditions of consciousness is not far.

We have explained that three types of reaction (perceptual, ideational and volitional) are "conscious," that is, they involve perception or thought as a part of the total process included between the stimulation of the receptors, and the muscular or glandular activities. The other two types of reaction: simple reflex and pure automatic reaction, seem to involve no consciousness, although other conscious reactions may accompany them. We must now compare these reaction types more closely, in order to discover, if possible, the reasons for the appearance of consciousness in the perceptual, ideational and volitional forms, and its non-appearance in the simple reflex and pure automatic forms.

Actions of the simple reflex type, as we have already pointed out, are due to neural transits involving the spinal cord or the brain-stem, or both, but not essentially the cerebral hemispheres, and probably not the cerebellum. Conscious reactions, on the other hand, do involve the hemispheres,[96] and it seems improbable

[96]Because of the fact that conscious reactions involve the cerebrum, there grew up the assumption that the cerebral neurons are specifically different in function from the neurons in other parts of the body, and that these cerebral neurons, in some specific way produce, or condition, consciousness. This assumption has become very thoroughly popularized, so that its eradication is a difficult task. Certain psychophysiologists have gone further, and adopted the phrenological assumption, that cells in different parts of the cerebrum produce different "kinds" of consciousness: visual consciousness being attributed to certain groups, auditory consciousness to others, imagination and memory to others, and so on: an obvious confusion of the concept of consciousness. These assumptions should be abandoned, because there is no evidence that different cerebral cells have different kinds of functions, or that the cerebral

that a reaction which does not involve the hemispheres, or some portion of them, can be conscious.

The significance of the connection of conscious reactions with the cerebral cells lies in the integrative control or dominance which these cells may exercise over the whole organism, not because of any qualitative peculiarity of these cells, but through the multiplicity of interconnections between them. Nerve current entering the human cord or brain stem through some afferent channel, and reflected outward from thence, without ascending to the hemispheres, has a limited range of efferent distribution, and its immediate effects upon the organism are consequently local, rather than systemic. Afferent current which reaches the cerebrum, however, may be reflected outward to any part of the body whatsoever, or to several widely different parts of the body, because the synaptic connections of the cerebral cells are so complicated that a circuit is possible from any receiving cell in the cerebrum to any of the cells which discharge into the brain stem or cord. Moreover, connections may be established in the cerebrum between any or all of the afferent-efferent discharges through it, so that the results of any afferent current reaching the cerebrum may be *systemic,* that is, may affect practically the whole organism.

The superior integrative control which is exercised through the cerebrum, we repeat, is not due to any peculiar sort of process in the cerebral cells, but is due to the arrangement of the neurons, through which a very complex system of synaptic connections is possible. We may compare the centers (cell groups) in the cord and brain stem to a series of local switch-boards, which are relatively independent of each other except in so far as they are connected through a grand central switch-board—the cerebrum—and through a supplementary switch-board—cerebellum. Yet the *kind* of activity which occurs in each switch-board is the same.

Consciousness, in short, is not the function, or the result of the function of specific nerve cells: it is a function of, or dependent upon, the systematic activity or cooperation of large groups of

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cells in general have functions different in kind from those of other nerve cells, except in regard to the relative energy of discharge, sensitivity to stimulation, and details of synaptic connection with other cells.

cells, among which are included in many cases muscle and gland cells, along with peripheral and central neurons. In other words, it is conditioned by the *integration* of the nervous system. Whether in any cases the activity of muscle and gland cells may be completely eliminated, without eliminating consciousness, is a topic for further investigation and discussion.

The energy of the reaction which conditions consciousness does not seem to vary with the vividness of the consciousness, but the degree to which the reaction involves the total organism does vary with the vividness. Above the strictly physiological or simple reflex, various degrees of integration of the nervous system are possible, involving the total effector system in corresponding degrees; and in this degree of integration we find the only possible physiological concomitant of attention, or the degree of consciousness.

The stimulation of the retinal receptors, for example, may set up a reaction which is definite and distinctive in that it is the response, spontaneous or habitual, of a certain limited part of the effector system, which is appropriate to that stimulation. This response may be a movement of the arm and hand, as in grasping the object, or a movement of the vocal organs, as in speaking the name of the object, or some other movement. If this reaction is connected with other reactions going on at the same time, through the cerebral synapses, consciousness of the object is present. If this cerebral connection is such that the other reactions are little modified, the consciousness of that particular object is of low vividness. If the connection is such that other reactions are modified generally, and in important ways, the consciousness is of high vividness: there is a high grade of attention to the object corresponding to the stimulation.[97]

Let us return now to the case of the ball player. In catching the ball, the reaction is primarily *to the ball,* but modified essentially by the stimulation from (among others) the runner. The

[97]Since the situation in regard to the simple reflexes differs only in degree, from the reactions with well marked integration, it may be that these simple reflexes through the brain-stem and cord are not absolutely unconscious, but merely so low in degree that the consciousness is negligible. This is a matter concerning which no decision can be made at present. That is to say, we cannot discover at present at what low stage of integration consciousness first appears.

player's attention is on the ball, and he is conscious in low degree of the runner. Neurally, the current from the visual receptors integrates the whole system; the neural path from these receptors to the muscles involved in catching is the main route: the current from the receptors stimulated by the runner is integrated with the dominant current, and is contributory to its effects. A moment later, however, the *runner* is the object of attention and reaction. The current from the visual receptors stimulated by the runner becomes the dominant current, and all other afferent currents, although integrated with this into the total efferent discharge, are subsidiary.

In effect, then, we may say, (1) that the neural condition of perceptual consciousness of an object is that the afferent current from the receptors stimulated by that object shall be integrated with the current coming in from other receptors generally, into a systemic discharge, in which the total stimulus pattern is related to the total reaction pattern through a unified neural pattern. (2) That the condition of focal *attention*, or maximal degree of consciousness at any time, is that the neural transit over the arc corresponding to the object shall be the *dominant* one: all other afferent currents being merely contributory to, or modifying, its efferent discharge, and the total efferent discharges being directed with reference to the specific discharge of the main route, and in furtherance of its results. These conceptions are not based upon specific hypotheses as to the physiology of the nervous system, for exceedingly little is known of that physiology. The conceptions are simple statements of the facts of animal response to stimuli: statements in terms of the known details of behavior of neurons.

CHAPTER XI

INSTINCT AND HABIT

§1. General distinctions.

Whenever receptors are stimulated, reaction occurs. This is the general law to which there are no known exceptions in the normal waking animal. The reaction is not to a single, isolated stimulus, but integratively to the total stimulus pattern of the moment, and is modified by preceding stimulations. Reactions at any moment may include the inhibition or checking of activities already in progress.

The specific results of stimulation are produced through neural transits, which originate in the receptors, enter the spinal cord or brain stem, may or may not ascend to the cerebrum, emerge from the cord or brain stem, and flow through efferent fibers to muscle cells or gland cells, modifying the activities of these cells. In the case of a reflex, the current entering over a certain route has a fixed route of emergence, so that the same stimulus produces always the same, or nearly the same result, regardless of what other stimulations may be occurring simultaneously with the stimulus of the reflex. In the reflex, the afferent and efferent neurons are apparently in permanent synaptic connection, or else the afferent neuron is in permanent connection with a central neuron, which, in turn, is in permanent connection with the efferent neuron, so that current sent in over the afferent neuron will be discharged outward over the particular efferent neuron, regardless of what other currents are flowing through the nervous system. In these cases, therefore, a specific stimulus will always produce a specific action. The knee jerk, or patellar reflex, is a typical simple reaction : a blow on the patellar tendon, in the normal animal, will produce a contraction of the extensor muscle of the leg, no matter what other stimulations may be acting on the animal, although these other stimulations may influence the degree of the contraction.

Perceptual and ideational reactions are more variable. Whether a specific stimulus: for example, the sound of a bell: will produce a certain action or not, depends upon the total stimulation present, and upon the predisposition of the central nervous system. A great range of alternative routes are open to the afferent current which has entered the cerebrum, because of the multiple synaptic contacts of the central neurons, and the variability of the connections at these synapses. Whether this or that route shall be chosen depends not only upon the other afferent currents pouring into the central nervous system, but also on factors which cannot be identified as yet, but which can be summed up in the vague term *predisposition.* The sound of the bell may result in your immediate rise from your chair: but if some one speaks to you at the same moment, the result may be different. The bell at ten o'clock may not cause you to rise, although the same sound at twelve causes that action.

Some predispositions to reaction are learned, or acquired by practice, that is: they are due, or largely due, to past reactions of the same sorts. Reactions in accordance with these predispositions are called *habits.* There are other predispositions which are not acquired[98] in this way, but which are due to heredity and growth, modified by previous reactions of other sorts only. These predispositions are called "innate," and reactions in accordance with such non-learned predispositions are called *instinctive reactions.*

§2. Drainage and habit formation.

In a normal individual, certain definite stimuli will usually produce definite reactions. If a word is spoken at your right, you turn the head in that direction. If light is flashed in your eye, you close the eye, turn the head away, or react in both ways. If a certain color is placed before you, you will make the reaction of saying "green," or some other vocal reaction. Some of these

[98]The actual meanings of the terms "acquired" and "innate" are liable to serious confusion. Innate predispositions are not necessarily operative at birth: many of them appear much later, and some are operative before birth. Predispositions acquired by the process of growth, and general reactions, and not dependent on the animal's previous reactions of the same type, are not "acquired" in the sense in which the term is technically used. *Inherent* and *learned* are much better terms.

reactions have been learned. You react by saying "green" when a Frenchman would say "vert": and a child who had not been taught the names of colors would say neither of these. Other definite reactions are instinctive. The child a few hours old will follow a moving light with its eyes, and will begin the sucking reaction as soon as its lips touch the nipple. Its nervous system is so disposed, through its growth and development, that certain stimuli cause definite reactions, through definite neural pathways. Yet reactions can be modified, so that a certain stimulus will produce a reaction which it formerly would not. This modification of reactions may be *learning,* or *habit formation.*

The possibility of habit formation is provided through the fundamental integrative tendency of the nervous system, which manifests itself in the simpler details of learning in a form to which we apply the term *drainage:* the tendency of a neural transit, when definitely established, to divert other transits from their normal efferent courses into its efferent channel. This drainage tendency is illustrated in a striking way by experiments which have been performed on dogs by Pavloff and his pupils. A normal dog, if hungry, shows a definitely increased flow of saliva, when he is allowed to smell or see food to which he is accustomed. Obviously, there is an effective reaction arc from the olfactory receptors, through the central nervous system, to the salivary glands; and the transit over this arc ends in increasing the activity of the gland cells. By means of a surgical operation, Pavloff brought the duct of one of the salivary glands of a dog to the outer surface of the cheek, so that the flow of saliva could be readily noted and measured. It was then easy to demonstrate that excitation by the smell of food produced salivary flow, but that the ringing of a bell did not. The dog was then fed regularly for some days, a bell being rung each time he was fed. After a certain course of this combined stimulation, it was found that merely ringing the bell would cause a flow of saliva. The simplest conclusion would be that a new arc had been made effective, from the auditory receptors to the salivary glands. The strong discharge to the salivary glands, due to the olfactory stimulation, "drained" into it the afferent current from the auditory receptors, which normally would have gone to effectors other than the salivary

glands, and made these glands the terminus of the auditory reaction.

The explanation as given is probably too simple. The auditory stimulation probably did affect the salivary glands in the first place, but not much: the major effects of the stimulation were produced on other effectors: muscles which erect the ears, and so on: or else diffused to large numbers of effectors with no great effect upon each. In either case, the efferent discharge to the salivary glands was relatively small. Now, with the strong efferent discharge to salivary glands over the arc from the olfactory receptors, more of the auditory transit is diverted to that particular effector group: and this having occurred once, increases the tendency for it to occur again, until finally a habit of discharge is formed from the particular reaction pattern, due to ringing the bell, over the customary afferent route and the newly formed efferent route, to the salivary glands. This habit is the tendency for neural transits, resulting from the same, or similar, auditory stimulus patterns, to pass, in the future, over the new efferent route, even when the olfactory transit, which originally "drained" the auditory transit into the efferent part of its arc, does not occur.

The general facts of drainage have long been known: it is not a new discovery that stimuli which originally did not produce a certain action could be made to do so by a proper course of training an animal. It has been known from prehistoric time, for example, that animals could learn to come for food when auditory stimuli were given, through the giving of these stimuli at times when the animals were being fed. It is, moreover, a matter of common knowledge that the visual perception of a lemon, especially of a cut lemon, will excite salivary flow in persons who have sucked lemons, although, of course, it would have no such effect on a person unfamiliar with the taste of lemon juice. The value of Pavloff's experiment consists in its putting a well-known fact in a simple and definite form, so that the mechanism is made plain. Salivary secretion following olfactory stimulation is usually listed as a *reflex,* and the most important transits involved are through the brain stem alone. Normally, however, the reaction is perceptual, or, at least, mixed, involving transits through

the cerebrum, with consciousness of "smell of food," or "food." It is probable that if these cerebral branches of the total transit were excluded, the reaction would persist, in that case becoming a pure reflex. In that case, however, the drainage of the auditory afferent current into the salivary efferent route would not occur: the salivary reflex could not be modified. Habit formation depends essentially upon synaptic connections established in the cerebrum, or cerebellum, or both. Hence, the name "conditioned reflex which is applied to new reactions, like the auditory-salivary, is misleading.

The modification of the auditory reaction in the dog is a clear illustration of the conventional distinction between instinctive action and habit. The original salivary reaction is described as instinctive: saliva flows at the smell of food, because it is assumed the dog's nervous system is by heredity predisposed to shunt the current of this particular olfactory origin through to the salivary glands. The instinctive auditory reaction, on the other hand, includes, among other details, the "pricking up" of the ears. The modification of this reaction in such a way as to produce salivary activity from auditory stimulus is habit formation, and the reaction thus established is a habit.

It is possible, however, that the olfactory-salivary reaction is not absolutely instinctive, but is also a habit, developed from the instinctive salivary reaction for food in the mouth. The contrast between instinctive action and habit has been overemphasized in the past. All habits are based upon instinctive action, and in the human animal, almost all instinctive action is modified by habit formation as soon as it is manifested. There may be a few instinctive reactions, such as sucking, which are little modified, and persist for some time in practically the form of their first appearance. In the lower animals, instinctive action, relatively little modified through life, is more common. But in every animal in which habit formation takes place, the modification of instinct is itself an instinctive process. The dog, for example, has a nervous system so constituted that the salivary reflex will necessarily modify the auditory reflex. The habit, therefore, is merely a more complicated instinctive reaction, or rather, an instinctive reaction depending upon a definite sequence of stimuli, rather than upon

a momentary stimulus pattern. The dog's nervous system is so constituted by heredity that the salivary reaction occurs when a certain olfactory stimulus is given. It is also so constituted by heredity that the salivary reaction will occur when a certain auditory stimulus, following a certain number of applications of that auditory stimulus together with the olfactory, are given. Are not both of these reactions, then equally instinctive?

The distinction between "habits" and "instinctive reactions" is a useful one, if we remember that habits are complicated instinctive reactions, and that habit, *i. e.*, the tendency of the reaction to any stimulus to be repeated when the stimulus recurs, applies to instinctive actions as well as to "habits."

§3. Instinctive reactions and instincts.

The fact that the reaction to a given stimulus pattern may be modified in a great variety of ways, implies that there are, at any time, a variety of routes over which the reaction may pass, which are equally possible, so far as the particular stimulus pattern is concerned; and that other conditions determine which of these routes will be followed. Consider, for example, the presentation of a red rose, visually, to an educated adult. From that stimulus pattern (the retinal image of the rose), a number of reactions are possible. The hand may be stretched out to grasp the rose; the gesture of refusing the rose may be made; the word "rose" may be spoken, or written; or any one of a great variety of reactions may follow this stimulus, according to conditions other than those of the rose pattern. What are the conditions determining the reaction?

These conditions include, in part, other stimuli presented simultaneously with, or just preceding, the rose-stimulus. If the spoken words "don't touch this" accompany the presentation, the reaction will be different from that which results when the words "take this" are spoken. If the rose is growing on a bush, along with a great many others, the total stimulation may determine a reaction different from that occurring when the rose is alone, in a vase. The presence of olfactory, tactual or organic stimulation may be effective in determining the reaction.

But over and above the stimulations simultaneously present

with, and those just preceding, the visual rose stimulus, the reaction is determined by habit. Other things being equal, the reaction which has occurred before will be the reaction of the moment; and the habitual or customary reaction may be the one which appears in spite of the fact that the attendant stimuli are very different from those which have previously occurred with the rose-stimulus.

The consideration of habit leads us back to the question why a certain reaction, now occurring as a habit, occurred in the first place. If the reaction occurs now because it occurred previously, why did it occur previously? And so we are led back to the problem of its first occurrence. And the reason for the first occurrence is found in instinct. The nervous system of the individual has developed in such a way, under the influence of heredity, that a certain stimulus pattern produces a certain reaction. Given this start, habit formation is possible.

Let us consider the reactions of a new-born babe. Normally, it cries, as soon as the cold air strikes it, or a brief time thereafter. If it did not cry, it would strangle. Perhaps the effective pattern is the coldness and the incipient asphyxiation, which together initiate the reaction which clears the respiratory passages of fluids.

Now this reaction is instinctive, and it is sometimes spoken of as *an instinct.* By "an instinct" we mean any combination of instinctive activities which produce a definite, and on the whole useful, result. In this case, the results include the production of sound stimuli which call the attention of adults to the presence and needs of an infant, and include also the clearing of the respiratory passages. The sucking reaction, mentioned in the preceding section is another so-called "instinct," whose result is the nourishment of the infant. Later, the walking instinct, the talking instinct, and a multitude of others, will make their appearance, and finally, the sexual impulse, whose practical result is the fertilization of the female by the male.

The instincts of the human animal, with the exception of those which appear at the time of birth, are *incomplete:* they require habit formation to perfect them, and fix them. In the lower animals, the instincts are much more complete, and many of them

remain through life practically unmodified by habit formation, while others are slightly modified. The first nest built by a bird, and the succeeding nests built by the same bird, vary only in accordance with the materials available, and with the weather, and the presence of enemies. In similar circumstances, the bird builds no better, no more efficiently in any way, the second or tenth time than the first. The young duckling, which enters the water a few hours, or perhaps sooner, after hatching, swims efficiently, and what improvement occurs is made very quickly. The walking of the young quadruped improves, in the main, merely by the gaining of muscular strength.

In the case of insects, there is no chance for improvement of their most complicated instincts, because they are active but once. This is true of the whole reproductive process of some insects. The male copulates with the female but once. The female bee may continue to produce eggs for several years, and the workers build many combs: but some wasps build but one nest, and the females lay but one set of eggs. Certain female wasps build nests of mud or paper, catch spiders and other insects which they stupefy with their stings, and deposit in the cells in their nests, deposit their eggs in proximity to the food so stored for the young, seal the cells, and then die before the young emerge. The young, upon hatching, go through the same cycles of instinctive activity, with no opportunity to perfect the activities by repetition.

The flying instinct of birds is apparently improved by practice, that is to say, habit formation, or learning. There is no "teaching" by the parent bird (popular theories to the contrary notwithstanding), yet the continued exercise of the crude flying instinct perfects and fixes it. The details of this sort of habit formation are perhaps more complicated than in the formation of the auditory-salivary reaction in the dog, although to an uncritical view such "practice" effects may seem much the simpler.

The hunting and fighting instincts of carnivorous animals also seem to be improved by practice, although it is impossible to say that this is really so. The improvement in such reactions may be really a matter of growth, and normal development of the neuro-muscular structure, and practice may have nothing to do with it.

The human talking instinct is one which shows modification

by habit formation in a very high degree. At almost eight months, on the average, sometimes earlier and sometimes later, the child begins to show a vocal activity quite different from the crying, laughing and gurgling characteristic of the younger infant. He begins to articulate syllables. He may commence with gutturals, such as "ga" and "kow:" or with labials such as "muh" or "pa." Often the infant, left to himself, will repeat a syllable over and over to himself. As the instinct develops, he adds other syllables, and makes combinations, and later forms sentences. These reactions are very soon modified through the effects of auditory stimulation (words spoken by adults or other children) chiefly, but also by visual, tactual and food (gustatory and olfactory) stimuli applied at critical times. The result is that the child acquires language, and the part played by habit formation in this process is sufficiently well illustrated by the fact that the child brought up among English speaking people speaks English, but if brought up among French speaking people speaks French. In fact, there is no doubt that children of any European stock, if brought up from birth among people speaking any language, civilized or savage, would learn to speak that language as well, at any age, as a person of the same age, of the race to which the language belongs: provided always that the auditory sensitivity and the general intelligence are equal in the two cases.

The list of "instincts" of human beings is large, as the list of practical results which are obtainable through instinctive activity is large. But since the results obtainable may be considered in larger groups, of a systematic sort, the instincts also can be grouped into larger instincts. A common grouping, or classification, distributes all instincts into two grand instincts: the self-preservative and the reproductive; a division based on the fact that all results obtained by animal reaction can be considered as either contributory to the preservation of the life of the individual, or to the production of new individuals, and hence to the preservation of the species.

Instinctive reactions, in fact, may be grouped under a varying number of classes, in accordance with our interests in classifying, as determined by the various classes of results which may be effected in the world. If we are interested in the distinction

between the satisfaction of sexual impulses as an end in itself, and the propagation and care of progeny as a separate end, we divide the "reproductive" instinct into the amatory and the parental instincts. If we are interested in the combat of men and animals, as distinguished from the ends attained by combat, we distinguish the "combative" or "fighting" instinct. If we are interested in the process which brings men together in social groups, and animals in herds or swarms, we distinguish the "gregarious" instinct.

The list of instincts given by McDougall is sufficiently illustrative of the various lists which have been prepared. McDougall lists flight, repulsion, curiosity, pugnacity, self-abasement, self-assertion, parental, reproductive, feeding, gregarious, acquisitive, and constructive instincts, with "a number of minor instincts such as those that prompt crawling and walking." He assumes, however, a further list of "general" tendencies towards sympathy, suggestibility, imitation, play, and habit formation.

The drawing up and discussing of lists of "instincts" is interesting, and may be useful, if we remember that the classifications are: (1) teleological, that is, determined by the ends or results of reactions, as these ends are discriminated, not by the animal itself, but by the classifier. The "instincts" are not strictly psychological nor physiological systems. (2) That the division into "instincts" is arbitrary, and that any classification which is based on real "ends," and which suits the purposes of our discussion, is as legitimate as any other. It is precisely like a filing system for documents: the system to be adopted is the one which makes reference convenient, and what is convenient for one purpose may be inconvenient for another. "Instincts" cannot legitimately be made the basis for "systems" of Social Psychology, or for any other theoretical constructions.

The fact that "instincts" are arbitrary groups, made for the logical purposes of the classifier, is made evident from the appearance of the same reaction in several "instincts" at once. The wolf, or the human animal, in pursuing game, may be exhibiting the "hunting instinct," the "acquisitive instinct," the "self preservative instinct" (since the food derived from the game will sustain his life), the "paternal instinct" (since the production

and protection of his progeny depend upon the securing of food for himself, as well as for them), and even the "gregarious" and "self preservative" instincts.

Any given instinctive physiological and psychological reaction may be, at different times, a part of any of the "instincts" in such a list as McDougall's. Fighting may be combat for life itself against an active attack. It may be a struggle for food. It may be a struggle for a female (or on the part of a female for a male) in pursuance of the instinct of sex gratification. It may be combat for a female, but in pursuance of the tendency to beget. It may be in defence of progeny. It may be directed to "gregarious" ends, in the case of an animal or a man who is threatened with expulsion from, or ostracism in, a herd or social group. It may be in performance of an acknowledged leader's command, in direct self-abasement towards the leader. Or it may be a means of self-assertion. It may be a means toward "acquisition," or a form of play.

So with running, hiding, and practically all the definite complex reactions of which the animal is capable. The particular "instinct" the reaction expresses is in part dependent upon circumstances of the actual reaction, but in large part on the whim of the one who classifies it. This must always be born in mind in considering "instincts." The more useful course is to consider instinctive reaction psychologically, that is, as definite reactions to definite stimuli; and in connection with the desires and other emotional states of the animal which reacts.

§4. Consciousness and volition in instinctive reactions.

"Instinct" is frequently contrasted with "intelligence:" but such contrasting is misleading. "Intelligence" is a term which has many meanings. It is sometimes defined as the "ability to profit by experience," or "ability to learn," which means either general ability to form habits, or ability to form habits of a useful kind. Now we have seen that the formation of habits depends upon an instinctive reaction foundation, and that it is itself an instinctive process. There is, therefore, no opposition between instinct and intelligence in this definition of the term.

The mistake has been made frequently of assuming that man, who has more "intelligence" than the lower animals, has less "instinct" or fewer "instincts." Such is not the case. The human animal is at least as richly endowed with instinctive reactions as any animal, and the chief difference is in the superior modifiability of human instincts. Which means, after all, merely that man has a richer instinctive endowment.

If we stress the modifiability of instinct as the characteristic of intelligence, we are not far wrong. But in this case, the discussion reduces to the mere application of a term, which because of its other connotations, is a constant danger to clearness of thought.

In a still more vague meaning, the term intelligence is applied to the capacity to react efficiently, that is, with advantage to the individual, in the circumstances in which the individual is normally placed. In this sense, we may discuss the "intelligence" of wasps, who act, apparently, through instinctive reactions of the extreme unmodifiable sort. In this sense, we apply the term to "intelligence tests," and some workers in the field of mental tests even speak of measuring "native intelligence," whatever that may be. A strong case may be made out for the claim that "intelligence tests," in so far as they are useful, really measure learning ability ("intelligence" in the sense first described), and that we rate individuals in intelligence through intelligence tests by assuming that they have been exposed to the same environment, in home, school and work, and that accordingly those who have learned the most, have the greatest learning capacity. For the present, however, it is safest to define "intelligence," as it is related to intelligence tests, as *whatever intelligence tests measure.*

Instinctive reactions sometimes have been assumed to be unconscious: that is, to be reflexes: and an opposition between conscious reaction and instinctive reaction is thus set up. Another opposition sometimes assumed is between instinctive and volitional reactions. Both of these are false, and any remnant of them obscures our understanding of the real nature of instinct.

There is no reason for assuming that the reactions of the duck-, ling, when it first plunges into the water and swims, are unconscious, or even non-volitional; or that the nest-building of the

bird or the wasp is non-volitional, or unconscious. There might be reason for such assumption if we knew that these animals were altogether incapable of volition, or of consciousness; or if we found in the human being, instinctive reactions which were unconscious. On the contrary, we find that in man, instinctive reactions are characteristically conscious, and many are volitional; and we are therefore forced to admit the possibility that in the lower animals, *if* they have consciousness, instinctive reactions are conscious, and *if* they have volition, some of their instinctive reactions are volitional.

As we have just said, all the instinctive reactions which can be studied are found to be conscious, and most of them volitional. The fighting reaction, whatever form it takes, and by whatever stimulus it is aroused, is highly conscious. The fighter is aware of his antagonist, and is aware of the activities he directs against that antagonist. He is aware of the anger, or fear, which is aroused by the antagonist, and if there is confusion in the fighter's consciousness, it is due to the vivid awareness of these emotional factors. Furthermore, the fighter's reactions are in most cases strongly volitional. He has the desire to injure his antagonist, or to prevent his antagonist from injuring him; this involves the anticipatory idea of the possible outcome, and full *consent* to the anticipated outcome in the one case, and to the *escape* from the anticipated outcome in the other. The strong *rejection* of an anticipated event is as volitional as is its acceptance.

In *flight with fear,* another instinctive reaction, there is always a high degree of consciousness, and a keen desire to escape anticipated harm. In a somewhat different reaction, frequently combined with the fear reaction, namely, startle (being startled), there is perceptual consciousness of high vividness, but no volition. Let some one fire a pistol behind your back unexpectedly. You "start" violently; it is by no means an unconscious reaction; you are keenly conscious of the sound, and your "start" is the reaction *by which* you become conscious of it. But there is no desire involved, and no anticipatory idea.

If we need to consider an extreme case, the sexual reactions offer illustration of instinctive reactions which are not only vividly conscious, but strongly volitional. These reactions are very

quickly overlaid by habit formation, but the instinctive basis may nevertheless be distinguished. The adolescent boy, when he begins to be "interested" in girls, is acting under the influence of fundamental instinctive tendencies. Whether he seeks their society and goes through the usual courting behavior, or whether he avoids them because of his interest,[99] his reactions are perceptually and ideationally conscious of girls, or a girl, and of a composite mass of data—visual, auditory, olfactory, tactual,—connected with girls in a direct or remote way.

These reactions, moreover, are volitional, and it is doubtful if any other reactions throughout his whole life will be as strongly volitional as these thoroughly instinctive sexual responses.

If there is any essential relation between consciousness and instinct, and between volition and instinct, it is certainly not one of antithesis or exclusion. The most important instinctive reactions are volitional (and, of course, conscious). We might reasonably adopt the proposal which has been made by several authors, that the term "instinctive" should be restricted to *conscious* unlearned reactions, thus distinguishing them from reflexes. At any rate, we must distinguish these two classes from each other, whether both are included under the term "instinctive" or not.

It is possible that only the conscious instinctive reactions are *modifiable,* and that the unmodifiable "instinctive" reactions, such as those of the wasps, are unconscious. If this should be true, we would have a basis for classifying the wasps' complicated behavior as reflex, instead of instinctive. But after all, the distinction between modifiable and unmodifiable reactions is probably one of degree. And the distinction may not hold. While it is undoubtedly true that only conscious reactions are relatively modifiable, it does not necessarily follow that all conscious reactions are modifiable, or that the degree of modifiability varies with the degree of consciousness. It may be that the bird, in building its first nest, is not only conscious, both of the materials it uses, and the results of its activities, but of its activities in

[99]The phrase "avoids them because of interest" is a cryptic one. The avoidance in this case is as specifically sex behavior towards the girls as is the frank seeking on the part of the other boy. The shy boy's reactions are perceptual and thought reactions of girls, or of sex, and the violence of his desires and other emotions is responsible for the incoordination of these perceptual and thought reactions.

building. The bird may even have an idea of a nest,[100] although it may have been hatched in an incubator, and never have seen a nest: and it may have a *desire* to build a nest. For there is no known reason why complex ideational reactions cannot be inherited, as well as the perceptual reactions which we know to be inherited.

§5. General principle of habit formation.

Certain general principles of habit formation have long been known, and were formulated before the reaction basis for perception and thought was discovered. These principles apply to *all* reactions which can be modified: to the reactions involved in playing tennis and billiards, swimming, and operating complicated machinery, as well as to those involved in studying geography and higher mathematics. We shall give here merely a brief summary of these principles, or laws, of learning, leaving the more extended development for later chapters.

First Law. Recency

The tendency for a given stimulus pattern to arouse a reaction which it has aroused in the past is greater, the more recent the arousal of the reaction by the stimulus pattern has been. This tendency may be counteracted by other forces, and is most clearly exhibited when the reaction tendency depends solely upon the preceding repetition. An illustration is the solving of a puzzle, which may easily be repeated immediately after the trick has been successfully done, but may be more difficult, or have to be relearned at a later time. In learning to dive, when a successful dive has been made, there is more chance of repeating it successfully a short time afterwards than a few days later. However, this result may be somewhat complicated by the effects of preceding unsuccessful dives, as these also tend to be repeated, and in some cases, where a number of unsuccessful dives have been made, the effect of these may disappear with increasing time-interval more completely than the effects of the successful dive. In the "associa-

[100] Of course, the bird may be incapable of ideas of any sort. We are not claiming here that the bird has ideational, or even perceptual, consciousness. But there is no ground for *denying* that it has both: and if it has ideas, it very probably has *innate* ones, that is, ideas *not* derived from previous perceptions.

tion test,'' where the reactor is required to respond to a spoken word by speaking the word first thought of, repetition of the stimulus word a few minutes later tends to evoke the same response word. This tendency is markedly lessened in the course of a few hours, and still more in the course of a few days, as demonstrated by the decreasing number of repetitions of the original response words to a list of stimulus words, as the time elapsing between the first and second stimulation is increased. This result again is not absolutely pure, since the other conditions which determined the response word on the first application of the stimulus, may remain efficacious for a certain time.

In terms of the nervous system, the neural pattern of a reaction tends to persist after the reaction, ready to become a pathway for discharge for the same stimulus pattern, but disintegrating as time goes by, unless re-excited. This may be figured as a continuity of the condition of the synapses acting in a given neural pattern, so that the discharge will be shunted over the same arcs in the same ways, when the stimulus pattern is presented again. With the passing of time, other reactions, using the same arcs, tend to modify the synaptic conditions.

Second Law. Frequency

The oftener a given reaction occurs as a response to a given stimulus, the stronger the tendency for the reaction to recur when the stimulus recurs, and the less effect the passage of time will have on weakening the tendency. In other words, repeating a reaction tends to fix it. Perfection in diving is obtained by repetition of satisfactory dives. The repetition of a list of simulus words several times within the hour, if the response word for each stimulus word is repeated each time, increases the chance that the stimulus words will evoke these same response words at a later time.

Third Law. Vividness

The higher the degree of attention given to the stimulating object, the stronger the tendency for the same stimulus to evoke the same reaction at a later time. In learning the response words for a set of stimulus words, ''inattention'' is a seriously disturb-

ing factor; the maximal tendency to repeat the reaction is secured by maximal attention. This law of attention is so well known that little explanation should be necessary at this point.

Expressed in neural terms, the "fixing" of a reaction pattern depends in an important way upon the integration of the nervous system in the reaction. The more completely the nervous system is integrated by the main arc involved, the more lasting the fixation.

Where several stimulus patterns are present, producing a total reaction, the tendency for the most vivid pattern to reproduce the reaction later is stronger than the tendency for the less vivid to reproduce it. If, for example, one is learning response words, as in the illustration above given, while persons are moving about in his field of vision, the best conditions for learning are where the stimulus words are most vivid. If at any moment, the visual paths become vivid, the fixation of the reaction to the auditory stimulus is decidedly interfered with. Moreover, the less vivid the minor stimulus pattern, the better. If, as may occur in some cases, a double reacion pattern occurs, so that there are in effect two minor systems of integration, more or less interconnected, the persistence tendency for each is less than that for either when occurring alone, and integrating the whole system in a more unitary way. One can learn spoken response words to auditory stimuli, while learning written responses to visual stimuli. But the process is seriously inefficient. Fully integrated reaction to the data which is to be "retained" is the optimal condition for fixing the reactions to those data. And this condition is the condition of focal attention to the data.

Fourth Law. Emotional Tone

Moderately strong emotional tone facilitates, in general, the formation of habits, either by increasing the retention, or fixation, of the reactions with which the emotion is directly connected, or by preventing the fixation of conflicting reactions. The discussion of the mechanism of emotion must be deferred to a later chapter, and hence the bare facts alone may be noted here. Not only pleasurable emotion, but all types of emotion have this general effect. And both pleasurable and painful emotions have been

widely employed in furtherance of the learning process. Reward and punishment are two practical ways of obtaining emotional response.

It might be supposed that certain types of emotion favor learning, and certain types are unfavorable. The respective merits of reward and punishment, for example, have been seriously argued; but the experimental facts bear out our supposition in this particular case: both reward and punishment are efficacious *in some circumstances;* and there can be no reasonable doubt that all emotions are positive in their effects, *provided* (and this is the critical point), *they are directly connected with the reactions it is desired to fix or to eliminate.*

In many cases, emotion is a disturbing factor, because it becomes connected with reactions other than the one which is to be learned. The boy, threatened with punishment in case he does not get his lesson, may be conning it over in a state of fear, or unpleasant anticipation, or anger, or excitement, with attention less on the lesson than on the future punishment, of schemes for evading it, or ideas of injustice, or some other ideational content. Obviously, if the fourth law holds, such a condition is unfavorable for the learning of the lesson, however favorable for the learning of habits of distracted study, of sullenness, or of revengeful plotting. Pleasurable emotion may operate in a similar way, being connected less with the reactions with which the teacher wishes it to be connected than with other, in general ideational, reactions.

The emotional tone, in short, is not only a positive aid to learning: it is, because of that very fact, one of the greatest detriments to learning; the difference depending on its being connected with the reactions to be learned, or with other reactions conflicting with them, or which occur at such times as to interfere with them, and to prevent their integration in proper form.

Fifth Law. The Limits of the Mechanism

Since learning depends upon the integrative function of the nervous system, the limits of learning and the basal capacity are set by the inherent characteristics of that mechanism. Regard-

less of the principles above explained, some individuals have a greater retentive capacity than others, just as some are muscularly stronger than others, or have stronger bones. Within the retentive limit, an individual's actual retention for any reaction will be largely dependent upon the recency, frequency, vividness and emotional accompaniments of that reaction: but better results will be obtained by some individuals than by others.

The limits, and general basal capacity, are dependent not only upon heredity, which determines the general character of the neuro-muscular system, but also upon the metabolic condition of the total organism at the time at which learning is in progress. The nervous system is apparently sensitive, not only to nutritional changes, and to fatigue conditions, but also to various chemical factors, due to functions of ductless glands, and failure in function of duct glands, and conditions in the digestive tract. Just what the range of variations in the integrative mechanism due to chemical factors of these sorts, and just what the range of chemical processes capable of producing these variations is, we cannot say. But that there are such variations is apparent; fatigue, sickness, indigestion, hypo-thyroidism, are distinctly unfavorable to learning, as compared with their opposite, "normal" condition.

It may well be that the organic conditions are effective through the modification of the conditions covered by the third and fourth laws. It may be that the man who never can learn as efficiently as another, does not succeed in integrating as thoroughly as the other man, or his emotions are less adequately enlisted. It may be that fatigue interferes with learning by *inhibiting* integration: This does not materially change the situation. It still remains that heredity and acquired organic conditions affect the formation of habits in an important way.

Sixth Law. Implicit Habits

It might be assumed that the proof of a habit is the occurrence of the reaction. Perhaps this has been assumed by some theorists, but it has never been assumed by the unsophisticated man or by the experimental psychologist. It is true that the occurrence of the reaction *may* prove the existence of the habit (this is not

always the case), but the non-occurrence of the reaction is no proof of the non-existence of the habit. One, for example, who has learned to dive as a child, and who has not indulged in that pastime for many years, may, upon "trying" again—that is, when stimulated by the old pattern of the water, the spring-board, etc.,—make a perfect dive. The habit persists, and since it is demonstrable by the reaction, we call it an *explicit habit*. Another who learned to dive later in life, and who also has not attempted it for years, may, in the familiar situation, make as ignominious a splash as was his primitive attempt. But that does not prove the loss of the painfully acquired habit. It may be latent, or *implicit*. He may, on another occasion, make a perfect dive, which is the unquestionable result of his "practice" of years before. The implicit habit has become explicit.

The existence of implicit habits is most strikingly illustrated in the realm of perceptual and ideational reactions. One will fail to recognize a person, a plant, a situation, with which one has earlier been entirly familiar. The formerly-established perceptual reaction to the stimulus pattern seems to have been lost entirely. Yet, on a subsequent presentation of the same stimulus pattern, the habit may reassert itself, and the formerly-learned perception may occur. The object, perhaps, is recognized; or the perception of it as such-and-such may take place, in accordance with the formerly explicit habit, without actual recognition in the true sense.

In the case of "ideas," apparent "loss of memory" for certain occurrences does not prove that "memory" is really lost. At a later time, the "memory" may come back. The habit upon which the "memory" is based was implicit: it now becomes explicit. The dependence of "memory" upon habit will be discussed more fully in the succeeding chapters.

The basis for the explanation of implicit habit, including implicit memory, is in part supplied by the principle of integration: but we cannot claim that the explanation is as yet complete. Implicit habit is a fact, and must be accepted as such. The occurrence of implicit habit in the realm of thought has caused some speculators unacquainted with the mechanism of thought to assume a mystical "unconscious mind," in which "ideas," con-

ceived as literal things, repose when not "in consciousness." One can see the stupidity of such an assumption by considering the exactly parallel case of the diving reaction. The "dive" you make today, and which is the result of your earlier learning, is not a "thing" which has existed all these years in some "unconscious" realm. It is a new act, produced today because of the habit formed in your nervous system years ago, and retained. So the "idea" which you think of today—perhaps remember where you put the letter you have long been seeking—is not a "thing" like the letter, which has been filed in the "unconscious:" the "thinking" is an act, like diving, which you "learned" before, and can now perform adequately, even if you could not perform it yesterday or the day before. Whatever there may be yet to be discovered in the nervous system in final explanation of implicit habits,[101] there is no more mystery about them in the thought-reactions than in the reactions of the diving type.

Implicit habits are perhaps based upon neural conditions similar to those underlying partly-formed habits. Very often, the continued repetition of a reaction seems for a long time to produce no results in the way of retention, yet often the results are there, and the habit may be almost formed, requiring but a little further "practice" to bring it to a point where it is explicit. Many of us have experienced the keen satisfaction of succeeding in learning some act, such as a stroke in a game, which has seemed hopelessly beyond us until just before we "came through" with it. Sometimes one becomes discouraged, and gives up after long practice, at a point where a little more trying would have caused success.

Habits which have been acquired, and then have been "lost," or have at least sunk to such a level of implicitness that they will not become explicit again by mere presentation of the stim-

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[101] A habit, even as it affects a single neuron involving its discharge to a certain neuron, or a certain group, out of all the neurons with which its axon is in synaptic contact, cannot be considered as resident in that neuron alone. For each neuron must function in a vast number of reactions, and hence in a large group of habits. Hence, the particular action of a given neuron at a particular time depends on the action of a large number of other neurons. Many conditions must be right before a habit can operate in a specific way and since habit is overlaid on habit upon the neuron, it is not surprising that habits should at times be "implicit," *i. e.*, not quite able to function.

ulus, may be relearned much more easily than they were learned originally. One can reacquire facility not only in games, but also in "intellectual" pursuits, such as mathematics, with comparative ease, if one has really had facility in the past. The less the retention for what has been apparently forgotten, the greater the work required in relearning, and hence the *relearning method* may be used as a means of measuring retention, in cases where the habit has become inoperative without relearning. For example, you may not be able to recall or reproduce stanzas of verse which have been "memorized" some months ago. Apparently they have been forgotten. But when you relearn them, the lessened studying now required, as compared with the studying required when you first learned the stanzas, is evidence that they were actually retained in part. And the difference between the former work in memorizing, and the work in re-learning, represents, or measures, the retention for the stanzas.

§6. Specific problems of learning.

When we approach the detailed problems of learning experimentally, we find that there are three distinct types of these problems, applying to the three types of learning, viz: I. Perfecting a response, *i. e.*, forming a new response or modifying an old one. II. Associating responses, or connecting them serially, and III. Simplifying a series of responses by eliminating "useless" details or "errors."

I. The first type is the primary one. Connecting responses serially necessitates responses to be connected, although the process of forming and connecting may go on concurrently. Learning the names of objects, and learning the vocabulary of a foreign language, are clear types of response formation, as is also the child's learning to grasp objects. In some cases, the action involved in the new response is not new, and the learning consists in attaching it to a new stimulus. In learning a German-English vocabulary, for example, the saying, writing, or thinking of the English words is usually a familiar action; but in the learning the action is made part of a new response for which the visible or audible German word is the stimulus. In such cases, there is usually a double response ultimately formed, namely, the say-

ing (writing or thinking) of the English word as a result of the German stimulus, and the German word-action as a result of the English stimulus.

A characteristic form of response formation of the general type in which an "old" action is attached to a "new" stimulus (*i. e.,* a stimulus which originally had not initiated the reaction) occurs in the *substitution test.* In one form of this test, a page is presented, on which are printed six geometrical designs (circle, square, cross, etc.), each design occurring several times on the page, in irregular order. At the top of the page is a "key," in which the six designs are presented in a row, with a different letter or digit under each. The reactor is required to write under each design, wherever it occurs on the page, the same letter or digit which is under it in the key. The speed and accuracy with which this is done indicates the reactor's capacity for this type of learning. Various types of material—pictures, colors, etc.,—may be used in this same way. In a simpler form of the test, a page of letters, consisting of several alphabets pied; or a page of ordinary text; is presented, and the reactor is required to cancel certain ones by "crossing them out," with a pencil stroke. For example, the reactor may be instructed to cross out *a* and *w,* wherever they occur. This is called the *cancellation test.*

The process of building up a response is frequently studied in laboratories by using such a response as throwing darts at a target, or making a billiard shot. The imperfect response, that is, the response imperfectly adapted to the purpose prescribed to the reaction, is gradually improved by repetition.

The range of response whose formation or modification, or both, is employed in the laboratory for experimental purposes, is extensive. The process of formation or of progressive modification of a response is usually described by the term *practice,* and through such practice experiments, various problems of practical importance are attacked. Such problems are: the determination of the length of time which should be devoted to practice at any one time; the interval which should elapse between practice periods; the effect of learning two or several reactions concurrently; and so on. The results of such practice work are commonly represented graphically by a "practice graph" (sometimes called a

"practice curve"), which represents the progressive changes in efficiency during the course of the total series of practice periods. Such progress may be shown in terms of the *time* required to perform the response, or of the accuracy of the response, according to conditions. A graph showing the progress in accuracy in operating an adding machine is shown in Fig. 15.

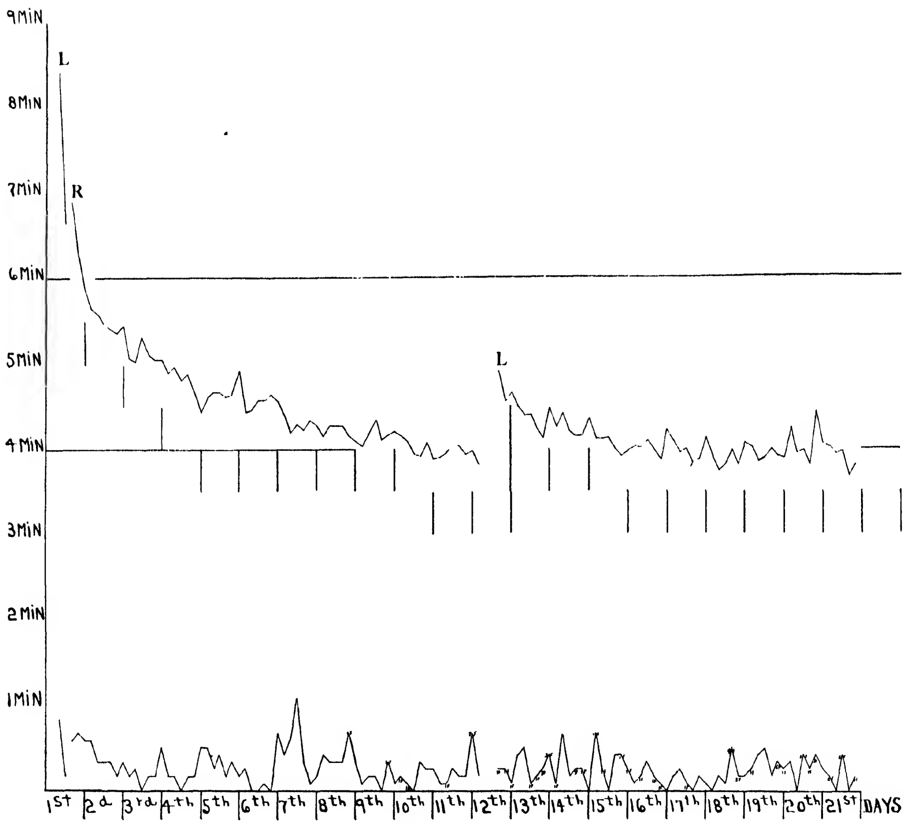

Fig. 15.—Practice curve for adding machine. By permission, from W. H. Norcross. The abscissae represent successive practice sheets, the ordinates the times required to list and add on the machine each sheet. The sheets were of equal difficulty, and each contained 90 four-place numbers. On the first day, two sheets were worked with the left hand, then two with the right. On the following ten days, four sheets were worked each day with the right hand. On the eleventh day two sheets were worked with the right hand, and then two with the left, and on the following ten days four sheets were worked each day with the left hand. The curve shows the increasing efficiency from day to day, approaching a level of maximal practice effect; and also the "transfer of training" from the one hand to the other. The irregular curve at the bottom represents the errors.

In experimental work, the response is always prescribed by the experimentor, but it is prescribed in different ways. The

response may be described to the reactor. He is told that he is to *hit the center of the target,* or that he is to *cancel each w* which occurs in the text. In this case, previously formed habits are brought immediately into play; it is assumed that the reaction of "trying to hit" or "marking" has been, to a certain extent, learned previously. The instructions then have the effect immediately of assisting in the integration of the reactor's nervous system in such a way that the stimulation (target or letter) will set off a reaction which will attain the required set in a certain measure (hit somewhere near the target, or mark w's with a certain speed).

In other cases, the reactor is given less specific instruction, or none at all. This method, called the "method of trial and error," is necessarily applied when experimenting on the lower animals and on children but is also used on human adults. In the case of the human reactor, he is given only the general instructions of the end to be attained, but nothing as to how to go about it. A puzzle is given him to solve; or he must find his way out of or into a maze; or he must find what key to press, from a large number, in order to turn a light on. The animal, in learning to open a food box, is "instructed" only by his hunger and the odor or sight of food. After many "errors" he will make the right response, and obtain food. On repeated "trials," the error becomes less, and eventually the "right" response will be made immediately.

In one form of the trial and error method, the animal is not required to learn any new reaction, or to modify any single response in an essential way, but merely to select the right response to make at the right point. The rat in the maze does not improve in ability to walk, to turn to right or left, or to perform any other action, but he learns to make the correct turn at each point, and to walk the correct distance in a given direction. Learning to run a maze is comparable to the stringing of beads, of various colors, in a certain order. The animal is capable of the individual reactions: learning is a matter of "stringing" them in the proper order. According to the most recent theory of animal learning, this is the only form of learning of which the lower animals are capable. Such learning is accordingly strictly

serial, and similar to that described under II. below. Human reactors not only learn to perform essential acts in the proper order, but also learn, by practice, to perfect the individual acts, and form new ones.

By any method, the improvement due to practice comes down to three points: (1) elimination of errors, (2) increasing accuracy of the "right" response, and (3) increasing speed of reaction. The sources of the first two of these forms of improvement are obscure, but are apparently due in large part to the emotional effects of success and failure, which in some way "fix" the successful response, and prevent "fixing" of the unsuccessful. If the reactor does not know the results of his reaction, he will make little progress on the first two points.

As regards the general condition of practice, the following points have been determined experimentally. (1) Short practice periods, with long intervening times, result in a saving of work (total practice) as compared with longer practice periods and shorter intervals. That is: to attain a certain level of efficiency, less work will be required, if it is done in short periods, separated by long intervals. Half an hour a day for three days gives better results than an hour and a half in one day. An hour every other day is better than an hour every day. But the limits of this advantage have not been determined. Doubtless there may be a practice period too short, and an interval too long; and the maximally efficient periods and intervals doubtless differ for different responses to be learned. (2) Learning of two somewhat similar responses concurrently sometimes decreases the efficiency in learning each. There seems to be "interference" in such cases. Rats work less efficiently on two types of problems when practicing both each day, than when working on either alone. In learning an English-Spanish vocabulary and an English-German vocabulary on alternate days, not as great progress would be made in each as when learned alone. But in many cases, there is no interference between two practice series, provided the general organic energy is not exhausted. Learning to swim does not interfere with learning mathematics, if time is properly apportioned to each. No very

general conclusion can be drawn at present, as to the degree of unlikeness required to prevent two responses from interfering.

II. The problem of serial learning has been attacked on human reactors through the so-called "serial memory" procedure, although many other methods of attack are theoretically possible. In the case of animals, threading a maze is the procedure most employed.

In experiments in serial memory, series of words, numbers, pictures, or groups of letters not making words, are presented visually or auditorily, and the reactor is required to "learn" the series, *i. e.*, to associate them together so that they can be serially recalled. In the case of familiar words and numbers, the problem is one of serial association simply, since the responses themselves are already "learned." In the case of nonsense syllables, usually formed like TOV and NUF, by inserting a vowel between two consonants, the individual responses have to be learned, and also associated, which makes the process somewhat slower.

Experimental results on serial associations so far bear on the effect of the *kind* of material (numbers, words, syllables, etc.) on the learning; and on the effect of the length of the series *i. e.*, amount to be learned at one time. As might be predicted, the more familiar the material, the more quickly it is associated. In increasing the amount of material (length of series) to be associated, the work required increases much faster. Inferences from the results of these experiments cannot be applied directly to other types of learning, although unfortunately such applications have been attempted. The fact that doubling the length of a series more than doubles the amount of work required for the learning of the series, does not imply that doubling the amount to be learned in paired associations would have the same effect. In learning a series, each term is associated with all the others: and hence the number of associative connections to be formed is very much more than doubled by doubling the length of the series. In a succession of paired associates, as in learning an English-German vocabulary, each member of a pair is to be associated with the other member only. The effect of increasing the amount to be learned depends therefore on the conditions described under the concurrent learning of different things (which do not apply

to serial learning) and especially upon fatigue and exhaustion produced by the previous learning; but not upon the specific factor just described in serial learning. School work in history, geography and similar subjects is much more closely allied to the paired association type than to the serial type.

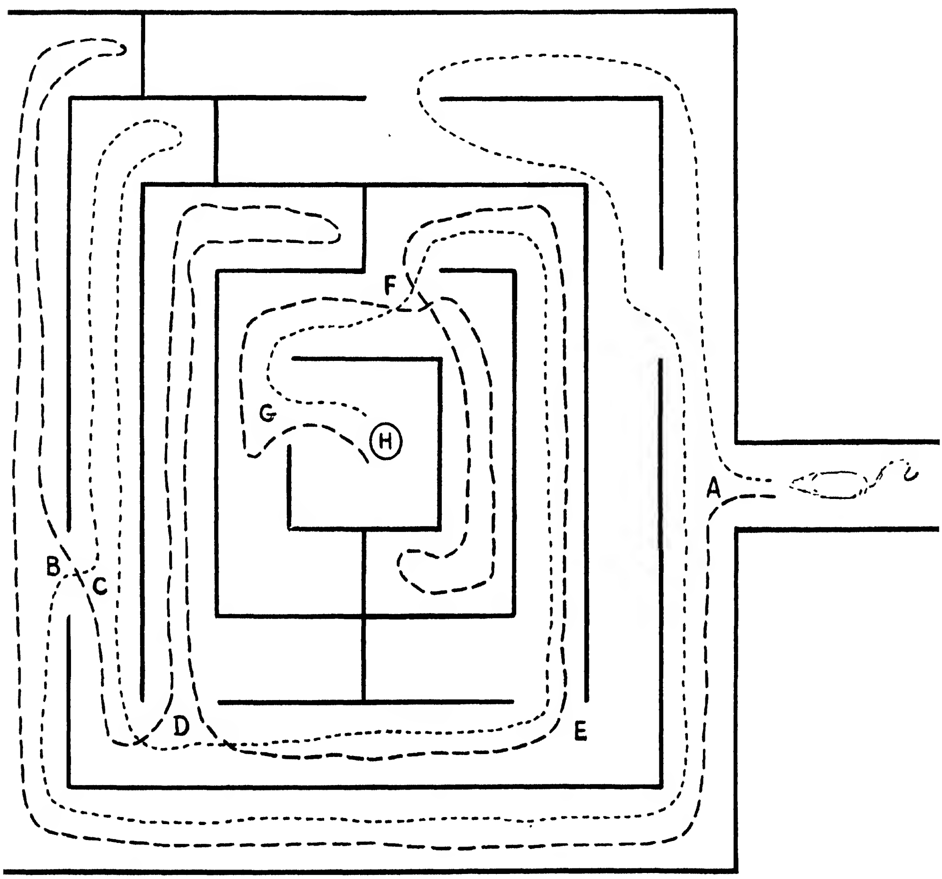

Fig. 16.—Typical pathways covered by a rat in a maze on successive trials in learning to reach food in the center. The rat put in the starting box, enters the maze at A and wanders about until he finds food at H.

The measure in serial learning is usually in terms of the number of repetitions, with form and duration standardized, required to learn perfectly a series, *i. e.*, to make it recallable without error. By measuring the repetition required to relearn a series after various periods of time, the curve of forgetting for

this form of learning has been determined. By learning a series made up of terms previously learned in a different order, it has been shown that there is association not only between adjacent terms, but also between those several places separated in the series.

The influence of length of practice period, and length of interim, have not been worked out for this type of learning.

III. The elimination of "errors" or wrong movements in a series may be illustrated from the case of a rat learning to "run" a maze (Fig. 16). The rat, entering the maze at A, wanders about, under the influence of hunger, and eventually finds food at H. Suppose that trials are made daily, each trial lasting until H is reached. After a few days, the rat makes the trip in shorter time, and begins to eliminate errors, until eventually, when introduced at A, he will run quickly by a definite route to H. In the figure, the routes of the first two trials in an illustrative case are represented. Suppose that, on the first trial, the rat turns to the right at A, and on the second trial, turns to the left, but returns by a loop to A again. No habit is as yet fixed: the rat may, on third trial, turn to the right at A, then to the left at the next opening, and go directly to E by a route shorter than either the first or second. But on the first two trials, the rat has *twice* gone down the alley to the left from A; only once down the alley to the right. If he repeats these two routes several more times, the effect of frequency alone will cause the tendency to turn to the left to predominate, and the loop to the right will be eliminated. The same process will cause elimination of the loops at B, D and F. If the rat does not, on the first few trials, find the shortest route from A to E, the route A-B-C-D-E-F-G-H will inevitably be established.

In human subjects, the elimination of error may proceed faster than in the rat, because of recognition. After once making the loop at the right of A, for example, the reactor would recognize the point to which he is forced to return, and the ideational processes involved in this recognition tend to inhibit the tendency to repeat the loop excursion on future trials. Although the precise nature of the recognition reaction is at present unknown, it is an important factor in human learning, and apparently entirely absent from the reaction of the rat and other infra-human animals.

CHAPTER XII

THE DEVELOPMENT OF PERCEPTION

§1. Direct and indirect perception.

Perception has been described in the loose terminology of the Anglo-German psychology, as "sensation plus imagination," with the further qualification that the pure sensation never (or seldom) occurs. In this formula, "sensation" means not the sentiendum, but the awareness of the sentiendum: which we have called, so far, sense perception: and perception means the being aware of complex objects, as including more than the sentienda which can actually be "sensed" at the moment of perception. Interpreted in such a way as to give the greatest intelligibility, the formula means that (1) perception, as it normally occurs, is more than sensation: and, (2) that the additional factor is imagination, or imagining. The first proposition is true; the second is false; and the best way to avoid confusion is to ignore the formula and consider the process of perception, as we have so far, as a reaction process.

We have been considering perception, up to this point, in its analytically simplest form, as the awareness of sentienda actually "presented" to the senses, ignoring the fact that we are usually aware, in such cases, of more than these immediately presented sentienda. We perceive color, for example, when certain visual stimuli act upon the retinal receptors; but in such cases we rarely perceive color alone: we perceive a colored object, and the object includes factors other than color, although these factors, in such a process of perception, are not presented to sense; that is, they correspond to no stimuli actually affecting receptors. It is now necessary to examine into the way in which such perceptual processes may arise. In this examination we must keep empirical facts constantly in view, and refer all our formulations to these facts. It is an easy matter in psychology, perhaps easier than in other sciences, to devise a set of terms, and then proceed to shuffle

these terms, using them in a logical game much as the pieces are used in the game of chess, losing sight of the realities these terms are supposed to represent, and arriving finally at formulations which very much misrepresent the facts. This unfortunate result can be avoided only by a strict adherence to empiricism.

Let us consider a simple case. Suppose that an orange of a ripe color is placed before your eyes. That which you *see,* strictly speaking, is just the color and the spatial form. But you perceive more than that: you perceive an orange: and an orange is much more than a spot of color. In order to be an orange, the object must have odor, taste, weight and certain tactual characteristics; and if your previous experience with oranges has been extensive, you perceive these characteristics with some degree of vividness, when you perceive an orange, although the only details *sensed* may be the color and space-form.

Suppose, for another illustration, that you hear the voice of some one in the next room. The *sensed,* or directly perceived, content is composed of sounds of certain pitches and timbers; but the total content actually perceived includes other (indirect) elements, perhaps visual, which make the sound the *voice of a certain person,* or at least the voice of a certain kind of person.

In the case of most sounds, it is easier to identify the total percept (the total content perceived) than it is to identify the directly sensed sound alone. If several plates are dropped in the kitchen, that which you, in the dining room, recognize first, is that chinaware has been smashed. A certain eerie note from next door, you recognize as the wail of a violin, as soon as it "enters" your consciousness. In neither case do you recognize the sound as such, and then refer it to the proper complex object. In many such cases, it is impossible to identify the sound at all by its intrinsic characters of pitch and timber, and it is recognized only by the indirectly perceived factors in the content. Very often, words spoken by one person are heard by another but not heard as words. The hearer merely grasps the *meaning.* This is the explanation of many cases of "mind reading," in which words whispered by one person, who does not know he is whispering, are heard by another, who does not know that he hears, but catches

the idea nevertheless, and catches it by a response to the auditory stimulation of the words.[102]

The process by which the content of perception initiated by various stimuli becomes complicated by the addition of indirectly perceived content to the directly perceived or sensed content, is to be designated as the *development of perception.* It would be simple to assume that the experience of the infant begins with sensing, or direct perception only; and that his perceptions are progressively built up from that level to the complexity of adult life: that all objects seen by the infant are at first merely color and form, and later acquire the complexity which makes them really objects, through the continued experience of the various factors. This assumption is, however, unwarranted, since the considerations of instinct and heredity justify the contrary assumption, namely: that the infant begins his perceptual experience with certain perceptions which are complex from the first. It is nevertheless a fact that the infant's perceptions are less complex than those of the older child, and that a process of perception building goes on throughout childhood, extending with lessening activity well into adult life; and we may legitimately assume that the further development of these perceptions proceeds in exactly the way in which it would if these perceptions had actually been built up or developed from really "simple," direct perceptions.

The infant's visual perception of an orange perhaps from the very first, includes more than the mere perception of color and visual form: how much more it is impossible to determine, although it is probably very little. In whatever stage of the development the infant's perception starts, it goes on developing from that point exactly as if it had been built up to that point from the very simplest stage. We may then illustrate the general process of perception building by tracing the development of a

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[102]In terms of the explanatory theory given below, these facts mean that there is, in the cases cited, no reaction for the sound as such, but a reaction for the total complex of content of which the sensed sound is but a part; and that this reaction is initiated by the sound stimulus alone. It might also be initiated by the visual stimulus alone. Of course, reactions for the perception of mere sound may be built up; but there is little occasion for the building of such reactions in the experience of the ordinary man.

certain perception from a hypothetical starting point at which it includes nothing indirect, but only the directly sensed details.

Let us suppose that an orange is presented to the infant's vision, producing a reaction from which we may infer that the color

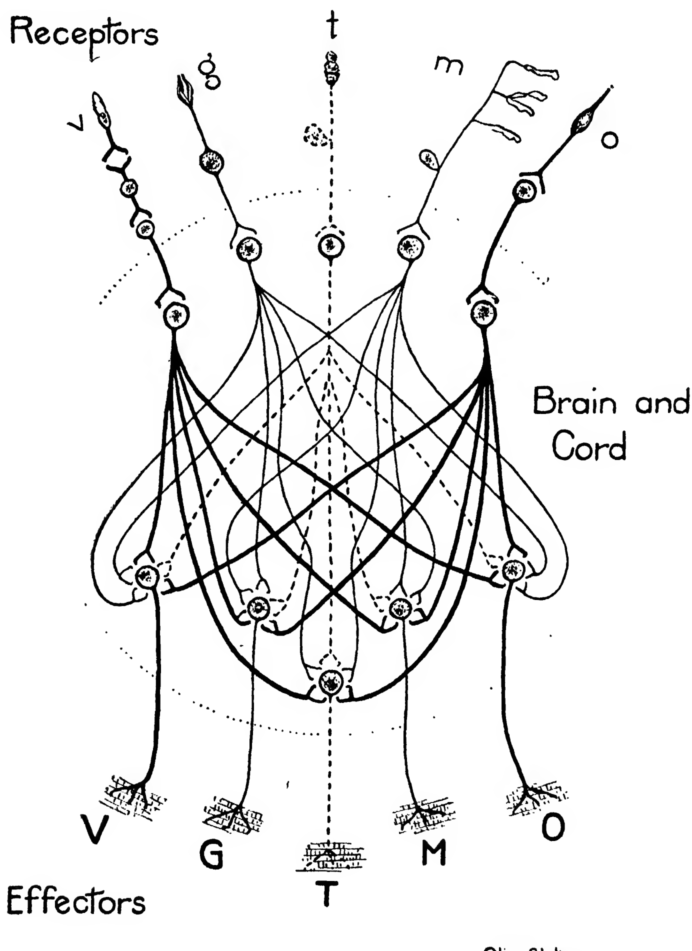

Fig. 17.—Scheme of the pathways and interconnections involved in the development of the perception of an orange. The heavy lines v-V, g-G, t-T, m-M, and o-O represent the assumed primary reaction-arcs from the visual, gustatory, tactual, kinesthetic, and olfactory stimuli respectively. The lighter lines represent the cerebral interconnections formed between these primary arcs.

of the orange, at least, is perceived. The visual stimulus we will indicate by v, the resultant action by V. Suppose that later the child is allowed to touch and handle the orange, with resultant

instinctive reactions. The tactual stimulations we will indicate by t, and the muscular stimulation by m: the corresponding reactions by T and M. The olfactory stimulations from the juice and peel, o, lead to still another reaction, O, and the gustatory stimulation, if juice is taken in the mouth, to the reaction G. We may neglect, for purposes of simplification, the possible temperature and visceral stimulations.

Since some of these reactions will at times occur simultaneously, as well as in immediate sequence, the neural parts of the reactions will tend to become interconnected, through the integration of the central nervous system, so that eventually they become several phases of a total reaction, and this total reaction may be produced by any one of the several stimulations which were originally necessary to produce all the reaction details. The child comes thus to perceive not mere color, but *orange,* when the orange is visually presented; not mere odor, but *orange,* when it is presented to the olfactory receptors alone. He may even perceive it as an orange when he feels it with his hands, without visual or olfactory stimulation; and he will therefore mistake other round, heavy objects for oranges until he learns to make the orange-reaction only when factors in addition to the shape are experienced.

Although we may call the perception of the orange, which is initiated now by visual stimulation, now by olfactory stimulation, and now by tactual stimulation, the same in each case, because in each case it is the perception of an orange; yet the three cases may present important differences, in that in one case the visual qualities, in another the olfactory, and in the third the tactual, are most vivid. The orange-reaction, therefore, is not assumed to be precisely the same in the three cases, but may have in each case one of the original reactions more pronounced than the other two, although all three original reactions are involved in each case.

There is, indeed, a wide range of variation in a single perception of this kind. In certain cases, the importance of the several direct and indirect factors may be significantly different, and the non-visual qualities may, in some cases, be more vivid than

the visual, although the visual content is direct, the other indirect. When the several direct sensory reactions have become amalgamated into a single perception, the exact details of this perception will be determined, not by the characteristic sense stimulation of the object alone, but by it in conjunction with the various other stimulations playing upon the receptors of other senses, and by the reactions (whether perceptual or ideational) which have preceded. The perception, even at the moment when it occurs, is not an isolated result of a restricted series of previous reac-

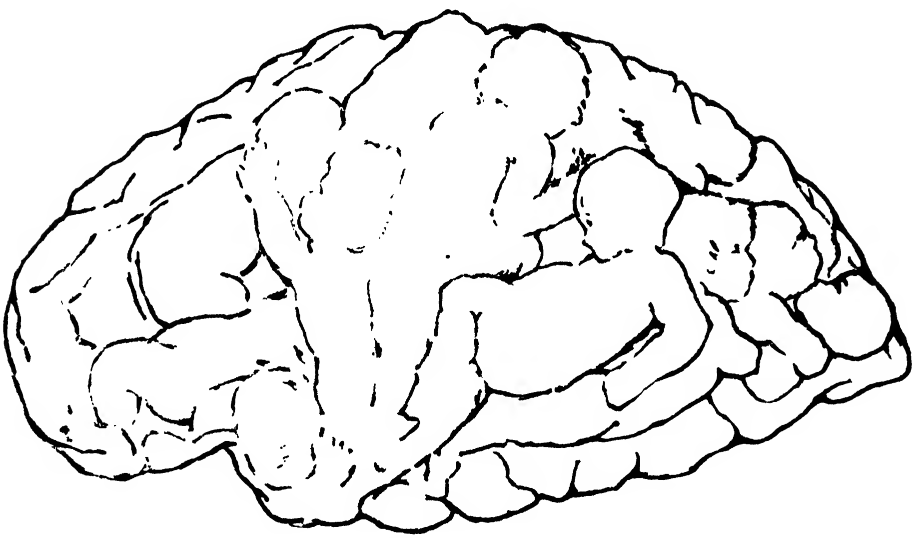

Fig. 18.—Hidden figures. (O. C. Slater, after Gudden's "Children of the Brain.") An illustration of the effects of previous reactions in determining the indirect factors in perception.

tions, but is connected with the whole complex of mind through the integration of the nervous system.

Along with the integration of the original perceptual reactions, goes a simplification and transformation of the reactions. Originally, the various orange-reactions involve extensive movements of all the limb muscles, and most of the other muscles. These activities are reduced, and eventually transferred to muscles which, at first, have a minor share in the reaction, namely, the vocal muscles. The most important part of the orange-reaction the child acquires in the course of time is the speaking of the word

"orange." In the perceptual reactions of both children and adults, language plays a rôle of very great importance.[103]

Whether in the process of development, perceptions ever reach a stage in which the muscular part of the reactions become eliminated entirely, we cannot now say. This is possible; and we may even make a guess at the mechanism by which the muscular activity is supplanted; but the discussion should be deferred until thought reactions have been discussed. In the development of perceptions, that is, during the process of learning, the muscular activities are certainly necessary; and if they are eliminated in some cases, the perceptions become thereby fixed in form, and cannot be further modified, except by a reinstatement of the complete reactions, that is, by the re-entry of the muscular activities.

In order that a perception may be as definite and vivid as possible, the muscular part of the reaction must be decided and definite. This principle has a wide range of practical application, and is nicely exemplified in the reading and transcribing of numbers. If one is engaged in reading numbers of several places on one sheet, and writing them on another, long numbers may be carried over without error if they are read aloud, or even if read silently with distinct vocal movements. If read with little muscular activity, as many people normally read (perhaps, as above indicated, in some cases with none) mistakes are much more liable to occur.

§2. Discrimination.

Discrimination is one of the most important aspects of the perceptual process. We have assumed, in the foregoing pages, the

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[103] The importance of the language reaction for perception, as well as for thought, is indicated by the fact that in any complete language, such as English, there is a word, or a word combination, for practically every thing which can be perceived or thought about, and that progress in accuracy in perception and thought goes hand in hand with progress in accuracy in the use of language. How slight may be the significant differences in reactions is indicated by the slight, but important, differences in words: beat, bate, bet, bat, but, boat, bought, boot, bite, bit, differ slightly in sound, and the differences in the reactions which produce them are slight; yet the educated man seldom slips, and makes the exact reaction required—speaks the right word for each occasion.

It must not be supposed that even in the case of the adult, the language reaction is the only reaction for the highly developed perception. All the striped muscles take part in one or another of our perceptions, although the language reactions rise in relative importance as perceptual discriminations we make become finer and finer.

fact of discrimination, without attempting to explain it. Difference thresholds of all kinds, for example, depend upon the reactor's capacity to discriminate intensities, qualities, positions and magnitudes: that is, to distinguish, in respect to some character, between two data which are very closely similar in that character.

The capacity to discriminate accurately where the actual differences are small is not the sole factor in "intelligence" or "mental capacity," but it is a very important one. The musician must be capable of fine discrimination of pitches, timbers, durations, and intensities. The artist must have keen discrimination of hues, saturations, and brightness. The important discriminations of the politician and the business man are more complex, and less capable of measurement, but none the less vital.

Discrimination in any specific case is nothing more nor less than accurate perception: perception of something as *this*, and not *that*. The capacity to discriminate is therefore fundamentally the capacity to make, in precise fashion, one reaction to one situation or object, and another reaction to a situation or object slightly different from the first. Learning to discriminate is the development of reactions essentially different, to definite, but only slightly different, stimuli. If, for example, I cannot discriminate between the note of 256 and the note of 259 vibrations per second, it is because I cannot make my reaction to the one always different from my reaction to the other, but am obliged to make the same reaction to both, or if I make two or more reactions, I make these reactions indifferently to either stimulus. If, by practice, I learn to discriminate between these two notes, what I really learn is to make one reaction (which may be the vocal reaction of saying "lower") to one, and another reaction (perhaps the saying of "higher") to the other. The invariable law is: *If I can discriminate between two things, I can make different reactions to them.* The proof of this law is that I can apply different names to whatever I can discriminate; for naming is one form of reacting.

The converse law, that whenever I make different reactions to two objects, I am discriminating them, may not be so easily proven, but it is inescapable. The only point of difficulty con-

cerns unconscious reactions, which we exclude from consideration. We speak of discrimination only when the reactions are *conscious* and different. The fact that our reactions to the same thing may show considerable variation is not a stumbling block. It is only where there is systematic variety, so that the reaction is different to the different objects, over and above the irregular variations in both reactions, that we speak of discrimination.

It is significant that where we find it important to discriminate between two objects, classes, or events, which have previously been treated as the same, or equivalent, a difference in reaction to the two must be introduced at once. In some cases, as in sorting colored papers, where first it has been sufficient to put all green in one pile, but now becomes important to distinguish between yellow-green, neutral-green, and blue-green, the differences in reactions are in part gross differences in reaction of limb or trunk muscles: putting them in different piles. In other cases, difference in word-reactions become the critical differentia. Whenever we decide to discriminate between two plants, animals, minerals, or theories, hitherto not distinguished from each other, we have to apply a new name to one of them; and this involves the formation of a new word-reaction to one of the objects.[104]

§3. Illusion.

From the fundamental facts concerning the development of perception, if no additional information were available, we would be compelled to infer that perception is not always *true:* not only that one may fail to perceive indirect content which properly belongs with the direct or sensed content, but that one may distinctly perceive indirect content which is not really a part of the object at all.

The first form of inaccuracy; *incompleteness of perception;* is

[104]The formation of a discriminatory reaction may be illustrated from pictures in which there is a "hidden" content. Figure 18, for example, may be perceived as merely a picture of a "brain," in which case the reaction is practically the same as that to a slightly different stimulus pattern in which there are no "hidden" babies. After the different reaction of perceiving "babies in the brain" has been made once, the picture will thereafter be perceived by that reaction, and not by the one by which mere "picture of a brain" is perceived. The differences in the two reactions are, for many persons, verbal, that is, speech-action differences: but they may be differences in the reactions of muscular systems other than the vocal.

indeed the rule, rather than the exception. Rarely, if ever, does one perceive every detail in an object of consciousness. The building up of perception does not, in general, reach such a stage of meticulous completeness. Nor would it be practically useful to do so. The optimal condition is the perception of those factors which are important for thought and action, and omission of the perception of those details, in objects and situations, which are relatively unimportant for further reactions. What is important for one person, or at one time, may not be important for another person, or at another time.

The second form of inaccuracy, *illusion,* or the perceiving of what does not exist in the form in which it is perceived, is also common, and is in general a source of danger to practical life, although it may not always be a detriment. Incomplete perception and illusions are due to several different causes, which are briefly described below.

I. Imperfect development, or wrong development, of perception. In learning to perceive, before the integration pattern is well established, the reaction is apt to be imperfectly discriminative, as when the child above referred to perceives a ball as an apple. In other cases, the learning process may firmly establish a wrong perception. Such errors are wholly matters for correction through education.

The various objects which, for practical purposes, should evoke the same reaction, are not all precisely the same. They do not stimulate the sense organs in precisely the same way. Yet, the reactions, in many cases, should be the same. The large, symmetrical apple, for example, and the smaller, crooked apple, should cause, in many circumstances, the same reaction. Both should be called "apple" (vocal reaction), and should be peeled in much the same way. Under some other circumstances, the reaction should be different. In selecting fruit for the table, the small, crooked apple should be placed in one dish; the large, symmetrical one in another dish. Under these circumstances, one would be called "perfect apple," and the other "imperfect apple." The differentiation of the reactions would be brought about in part by accessory sensory stimuli; in part by ideational reactions preceding the perceptual.

So, too, the child should make, under some circumstances, the same reaction to the apple and the ball. He should catch the one, when tossed to him, in the same way as that in which he catches the other. Yet he should not try to eat the ball, nor call it apple. Erroneous perception, in cases such as this, consists in making to one object, the reaction appropriate to a somewhat different object, in cases where it is *more useful* to make a different reaction.

II. Different objects may stimulate the receptors in ways so nearly alike that differential reactions can never be built for them. That is to say: there is no possibility of discriminating them, and a properly developed perception is brought about by the wrong object. Illusions of this sort are most striking in the realm of space perception, although they are found in various realms of experience. The illusion of depth produced by the pictures in a stereoscope is due to the fact that the images of the two pictures on the two retinae are precisely such as a real scene, having depth instead of the flatness of the photograph, would produce. Even in single pictures, the artist, by making the details such that the stimulus to the eye is closely like that which would be produced by real objects and distances, is able to give an illusory perception of depth or solidity. Other illustrations may be found in the realm of sound. If two persons' voices are indistinguishably different, either person may be perceived, upon hearing the voice of either.

III. Perception of a complete object may occur, when actually only parts or fragments of an object are presented to the sense through which these fragments are perceived. A person in dark clothing, seated before a dark screen, from which a large part of the clothing is indistinguishable, even with close attention, is frequently perceived as a complete person, and no notice is taken of the fact that a large part of the figure is indistinguishable. The face, hands, perhaps the feet, and certain parts of the clothing being perceptible, and in the natural relation to one another, the whole figure is perceived. This form of illusion is frequently employed in pictorial advertisement, where for example, a few details of a woman, clearly presented, cause perception of a woman, and not perception of detached parts of a woman. Various other

illustrations of the completion of objects in this illusory way may be found if we look for them. This form of perception is different from the ordinary cases only in that the indirectly perceived content is content which, if presented, would be content for the same sense through which the direct content is perceived. Certain visual details, for example, when presented, cause the perception of other, nonpresented visual details. In the case of the perception of the orange described in section 1, indirect details were assumed to be of modes other than those directly perceived: but the method of perception is the same in the two cases. A part of the total, original stimulus produces the complete reaction.

IV. The reactions to certain objects, and hence the perceptions of these objects, may be modified by stimulations due to other objects simultaneously present. The length of lines, or their directions, may be wrongly perceived because of the effect of other lines in the field of view, although the actual stimulations from the wrongly perceived lines are not modified thereby, and although these stimulations are not the same as would be produced by lines of the length or directions perceived. Errors of this sort are most conspicuous in the field of vision, although they undoubtedly exist in all departments of perception.

"Contrast" effects in magnitude of area, as when rectangles are compared with each other, are also found. A square of one inch diameter looks smaller when placed between two large squares than when placed between two smaller ones. Contrast in brightness in some cases is due to the same sort of reaction modification; a square of gray looks darker on a white surface than on a black surface. In some cases, this effect is enhanced by actual adaptation change in the retina, but it can be obtained under circumstances which exclude adaptation. Certain color combination effects also are, perhaps due to the same sort of cooperation of stimuli.

Certain letters in a word may be wrongly perceived, and the word read as if spelled with the substituted letters, because of the stimuli due to other letters of the word. It is partly on this account that accurate proof reading is difficult. One wrong letter

in the body of a word is seen as if right, because of the stimulation of the other letters.

This influence of simultaneous stimulation is widespread. A painted ball, which alone would not be perceived as an orange, may be "mistaken" for (wrongly perceived as) an orange, if the word orange is spoken as, or just before, the object is presented. And this occurs without any "ideas" intervening. A scarecrow's head, topped by a sure-enough hat, and just showing above a wall, may be perceived as a man's head, where the hatless head would not be so mistaken. A polished monkey-wrench, held by some one in the position of a pistol, may be perceived as a pistol, in spite of the large visual difference between the two articles.

These effects are really illustrations of the general principle of integration, and of the particular aspect of the principle which is, that under normal conditions, our reactions are not to single stimuli, or small groups of stimuli, but to large stimulus-patterns, involving all of the senses.

V. Failures to integrate the direct content are in a large and important range of cases responsible for wrong perceptions. The person fails to notice details which are directly presented, and which if noticed, would exclude the wrong perception. This is the grand source of errors in testimony on the witness stand, or off of it; and the success of the sleight of hand performer and the spiritualistic "medium" is due directly to it. The causes of this failure of integration are numerous and variable. In many cases, they are thought-processes, which have their origin in earlier stimulations, or they are strong emotional reactions. The man who has been led by his desires, or by skillful suggestion, to expect to perceive certain things which are to be presented in part directly and in part indirectly, will usually perceive those things; and the direct factors which would prevent the perception of that particular indirect content will not be perceived. Aside from any thought processes initiated previously, emotions of astonishment, fear, anger, horror, etc., so involve the integrating mechanism as to prevent the complete perception of stimulatory factors, and hence several witnesses of an unexpected event may have totally different perceptions. The fallibility of testimony due to these causes is well known.

The sleight of hand performer (prestidigitator or magician) depends in part upon arousing ideas which will facilitate imperfect perception; but in large part he employs purely perceptual means. By movements of his wand, hands, head, or body, or by the activity of his stage assistants, he "directs attention" to the details he wants to be seen, and away from details he does not want seen. This phrase "directs attention to" means nothing but the fact that by definite accessory visual stimulations, he causes certain parts of the total visual object to integrate the nervous systems of the spectators, so strongly that the transits belonging to certain other parts are completely drained off into the dominant transits, and these objects reduced to the lowest limits of vividness. In the total stimulus-pattern, only a limited part is efficacious in determining the details of the reaction. The afferent currents from the remaining stimulations, although integrated into the total discharge-pattern, serve only as general increments to the total current flow, and exercise in the total reaction none of the tendencies toward definite reactions which they would exercise if acting alone.

Much the same situation arises in the case of the sudden and unexpected event: the automobile accident, or the murderous attack. Here, through the suddenness or the intensity of certain stimulations, other stimulations are "crowded out:" their afferent currents are completely assimilated in the general integration. In the spiritualistic seance, ideas, of an anticipatory kind, play the leading role.

VI. Emotion and expectation are productive of illusion even when failure to perceive sensory content is not an important condition. A sound may be heard as coming from the expected direction or object, although nothing is offered to sense, which could produce a perception of any direction. Ventriloquism depends upon this tendency. Ghosts are also largely due to the same cause: certain fragmentary visual presentations being supplemented with the indirect details essential to a spectre. It is, however, true that in many cases of ventriloquistic and spectral illusions, there are stimulatory details which would destroy the illusion if they were perceived, the illusion being really of the type described under IV above.

§4. The conditions of accurate perception.

The consideration of illusion outlines sharply, by a process of elimination, the conditions under which perception is most accurate: the conditions, therefore, most satisfactory for scientific observation. The maximally disturbing factors are strong emotional states, biasing ideas, unexpected stimuli, and lack of training. These, it is obvious, must be excluded as far as possible.

Training in the specific type of observation required may be obtained, and is essential. A high degree of training in one line of observation is not sufficient preparation for observing along another line. Sometimes it is a positive disadvantage. The botanist, however highly trained in the observation of plants, is not qualified thereby for the making of psychological observations, and, conversely, the training of the psychologist, however thorough, does not fit him for botany. Long and thorough training in the mathematical aspects of physical science is apparently a positive impediment to observation in certain lines of psychological investigation: this, at least, seems the only explanation of the fact that the scientists who are dupes of spiritualistic mediums and of the demonstration of telepathy, levitation, and kindred mystical forces, are almost without exception mathematicians, physicists and engineers.

The avoidance of emotional disqualification is not a simple and easy matter. To a large extent, the emotional tendencies of the individual are hereditary, and not greatly modifiable. Yet some improvement may be made here by a technique which can be described here, which will be made intelligible by later consideration. First of all, one must obtain a clear idea of one's emotional difficulties, and must then form and think attentively, from time to time, the idea of being free of these emotional faults. Really, such a process is an act of will, of the typical sort. To the anticipatory idea of certain emotional traits is added the desire of possessing those traits, and assent to the desire. The effect of such volition may be large or small, but as we can see from the standpoint of the relation of nerve integration to action and consciousness, an effect certainly will be produced. The excitable, impulsive man can become less so by willing to be less so; and the depressed, apathetic man can become more sanguine if he

wants to. Of course, the removal of the conditions, whether environmental or physiological, which predispose to detrimental emotional states, is the first consideration. The scientist, whose work suffers from emotional faults due to unhappy family life, improper food, use of alcohol, or excessive thyroid secretion should first remove these causes as far as possible, before attempting "self control." One removes as many obstacles as possible from the road before overhauling the engine in preparation for the climbing of the difficult grade.

Biasing ideas are the more common sources of defective observation in scientific work, and in less formal perception. If you have a theory of what should happen under certain conditions, you are very apt to overlook details of the real happening, and to supply details falsely, in so far as the real details do not fit your theory, and the fictitious ones do. Moreover, you are predisposed to overlook defects in the conditions of the happening, and assume that the actual conditions, which may produce the expected happenings, are the conditions which your theory assumes. Much defective scientific observation has resulted from such ideational error. The removal of bias is a procedure very similar to the improvement of emotional conditions: in fact, the predisposition to bias is largely an emotional matter. The *will* to be unbiased is the efficacious thing, and this will must be based on a clear understanding of the nature of scientific hypotheses. We need to remind ourselves frequently that hypotheses are only suppositions made in order to be tested, and we need to remind ourselves also of the importance of being as pleased at finding that a hypothesis does not "work," as at finding that it does "work," even though we have constructed the hypothesis ourselves. Only through the active will to be unbiased: the will to have no emotional attachment to hypotheses, and to expect observations to substantiate them no more strongly than we expect the observations to disprove them: can the observer attain to an impartial attitude.

The avoidance of unexpected stimuli is the outstanding function of scientific method. Observation of uncontrolled events is useful in science, principally as a means of suggesting hypotheses and experiments. But experiment is the real foundation of

scientific certainty. Having formed a hypothesis, we proceed to arrange the conditions so that a certain group of events will happen: certain data will be produced. Foreseeing the event because we have arranged it, we are prepared to make a definite discrimination, namely, to observe whether a certain definite event does or does not occur as a part of the phenomenon: whether a certain datum does or does not appear. The integrative mechanism is prepared to react in one of two definite patterns, to be determined by the presence or absence of a definite detail in the stimulation pattern.

The difference between experimental observation and uncontrolled observation may be illustrated from the murderous attack previously mentioned. Several witnesses of a shooting affray may differ in their testimony as to which of two men drew his gun first. The unexpectedness of the event prevented accurate observation, and there is no necessary implication of mendacity on the part of the disagreeing witnesses. If, however, these witnesses had been posted in advance in positions favorable to observing the shooting; if the point, direction and moment of encounter of the principals were known in advance to the witnesses; and if they had been instructed to watch for this one specific detail, and to record their observations at once; they should agree in their reports. The unanimous testimony should be that A drew his gun in response to B's drawing, or commencing to draw; that B drew in response to A's drawing, or beginning to draw; or that both drew on sight, without either waiting for the action of the other. Discrepancy in the report would mean that one or more of the witnesses are gravely defective in vision or in intelligence: or else that one or more are lying. The degree of certainty which we may allow to the report of any one observer, either in everyday affairs or in the laboratory, depends upon the truthfulness of the observer, and the degree of control actively exercised over the events on which the report is based.

§5. Meaning and symbolic perception.

It is possible to discriminate the direct content from the indirect content in perception, and in that case we call the indirect content the *meaning* of the direct content. In the case of an orange

visually presented, for example: the disc of color, which is the whole of the direct content, may be discriminated from the solidity, weight, odor, juiciness, sweetness, and whatever other indirectly perceived content gives the disc the orange characteristics, and we then say that these are the *meaning* of the visual presentation; or, we say that the disc of color *means* an orange. Conversely, the color disc is the *symbol* of the orange.

These terms are seldom applied, however, to the simple cases of concrete objects, that is, to objects such as the orange, which are composed of data localized in the same space. Rather we tend to restrict the usage to cases of complex objects, or contents which are composed of a concrete object (the symbol) together with other objects related to it in a variety of ways, other than by spatial coexistence. The name of an object, for example, is a symbol, and the object is its meaning. The American flag is the symbol of the nation, or of a certain group of national characteristics. In perceiving the flag, we perceive more than a striped piece of cloth hanging from a rope. One perceives it as the American flag; and so, one perceives the name of Napoleon Bonaparte, not as the mere sound which it is for the auditory sense alone; one attends little to the sound, but perceives the name of an admirable military commander or of a cruel monster (according to one's historical viewpoint). One does not discriminate between the symbol (the sound) and the meaning (the perceived characteristics): one perceives the two as a unified content. Discrimination is possible, however; we may by a series of thought reactions, separate the direct from the indirect content, as we are doing here, and set the symbol over against the meaning.

In the use of names, we are producing perceptions which differ very much from those to which we have hitherto confined the discussion. In the early perceptions of the child, and in our own perception of many concrete objects, the direct content is focal in consciousness. In the perception of objects through names, the name itself, if familiar, that is, if it has been reacted to frequently in the same way, is usually out of the focus, and the meaning is focal. This sort of presentation pattern is not essential to symbolism: in perceiving the flag, for example, the visual details are usually focal; and even in perception based on names, the name may

be focal. But the non-focal perception of a symbol is frequent, and in some cases the symbol cannot be made focal, although the perception based on it may be definite and important. In such cases, it is convenient to call the symbol a *sign,* reserving the term symbol for the cases in which it may be focal.

Suppose that in the course of a conversation with some person you inadvertently make a remark which especially interests him, or which irritates him, or pleases him. In many such cases, if you are looking at his face, you *perceive* that he is interested, or irritated, or pleased, although you do not know *why* the remark had the effect it did have. In such cases, it is frequently impossible to detect the *sign* of interest, irritation, or pleasure. Yet, the sign existed, as a change in his face, which stimulated your vision in such a definite way as to produce the perception.

We cannot say that it is impossible that one might learn to perceive such signs. We should rather incline to the assumption that it is possible. Nevertheless, most persons have not learned to make the discrimination, and the attempt to do so—to catch the facial changes as facial changes—uniformly interferes with accurate perception of the meaning.

The pseudo-science of character analysis furnishes copious illustration of the possibility of perceiving meanings without perceiving the signs thereof. Character analysis began as phrenology: the theory and practice of reading traits of emotional character, and mental capacities, from the "bumps" or superficial details of the skull. Although this brand of character analysis is still actively exploited, it has been overshadowed of late by newer systems which read "character" in the shape and line of the face; the size and form of the nose, mouth, eyes, and even the color of the hair and eyes, and other like details. Of course, such "character reading" is impossible: an elementary knowledge of psychology and the laws of heredity assures us of that: and the possibility of developing any such system is too small to be seriously considered. Yet the systems flourish, and their apostles wax fat on them.

The explanation of the financial success of the promoters of certain systems of "character analysis" is in part similar to that of the persistence of spiritualism. The dupes never really check

up on the claims of the exploiters. Corporations pay thousands of dollars to clever exploiters, for the "character analyses" of their employees, and in many cases pigeon-hole the findings, while in cases where some attempt is made to use the findings, no scientific estimate of the practical outcome is made. Yet, it seems probable that some "character analysts" do make shrewd estimates, with a certain validity, of the characteristics of some of their patients, and that these cases impress persons who observe them.

Most of us, as a matter of fact, make "character estimates" of our friends and acquaintances, and even of chance met individuals, and some of us have more nearly accurate perceptions of this sort than do others. But we make these estimates, just as we observe the emotional changes in others, without discriminating or identifying the signs at the bases of our perceptions. Any serious attempt to discriminate signs, in the present state of scientific knowledge of the subject, interferes with the accuracy of the perception. We have learned by experience to make certain perceptual reactions to certain stimuli; but we have not learned, and at present cannot learn, to discriminate the subtle details corresponding to the essential points in these stimuli.

The signs of character, like the signs of emotion, we know are physiological: they are primarily movements, not only of the facial muscles, but of the vocal muscles, and of the body generally. We estimate personal characteristics from the voice, the posture and walk, and the movements of the arms and hands, as well as from facial expressions. Secondarily, the effects of previous actions, in the lines of the face and the attitude of the body, perhaps a certain characteristic of the voice, are important physiological traces. Anatomical characteristics, like hair and eye color, and the size and shape of organs such as the eye and ear, which are not affected by use, and the conformations on the bones of the head and face, have absolutely no known sign value, except as signs of racial origin. If we were in any doubt on this point, the way in which most "successful" systems of character analysis contradict each other, by assigning quite different characteristics to the same anatomical detail, and the same characteristics to quite different detail, would be sufficiently conclusive as to the present meaninglessness of such anatomical configurations.

No system of character reading by physiological signs has been devised, and such a system can be devised, if at all, only through prolonged psychological and genetic investigation. Any scheme which might be constructed by the type of persons now exploiting "character analysis" would be an actual detriment, since attempts to use it would prevent the "analyst" from making use of the actual and undiscriminated physiological sign. The bogus anatomical systems, however, do not interfere. The "analyst," when he really makes an accurate reading, does it just as you or I would: through the physiological signs, to which he pays no attention: and then he finds in his anatomical system the details which confirm his judgment, ignoring those which do not. And it is quite possible for an ignorant person to be a faker in this way without being aware that he is faking.

Another type of definite perception through imperceptible signs is that in which objects which are brought near a blind or blindfolded observer are recognized, or an object is recognized without the object being distinctly "sensed." In one experiment of this kind,[105] four frames, a foot square, were used. One was filled solid with wood, one with lattice work, one with wire netting, and the fourth was completely open. Three blindfold reactors discriminated these frames correctly, when brought near the face, in 90, 68 and 94 per cent of the cases respectively.

In this experiment, the discrimination failed when the reactor's ears were stopped; indicating that the signs were really auditory, although not perceived as such. Variations in the reflection of sounds by the solid wood, lattice and netting, and absence of reflection by the other frame, could conceivably supply different auditory patterns, provided incidental sounds were present to be modified. If conducted in a practically soundless place, the discrimination would therefore be expected to fail. However, other tests on different reactors have shown that discrimination of this sort is possible when the ears are stopped, thus raising the hypothesis that thermal signs may be effective (heat radiated to or from the object being the stimulus) or that air pressure, result-

[105]MacDougall, *American Journal of Psychology,* Vol. XV, p. 387.

ing from the movement of the object as it is brought toward the face, is responsible.

In any case, the experiments clearly demonstrate perception through unperceived signs: in which one is conscious, not of the data actually presented, but of its "meaning."

A somewhat similar case of symbolic perception has been found in experiments with the spatial illusion figure known as the Müller-Lyer Figure.[106] In this figure, the short angular lines produce an appearance of inequality of the two parts of the line when they are actually equal. It has been found that the illusion may be produced when the short angular lines are so faint as to be undetectable by the reactor. Although imperceptible in themselves, they nevertheless change the total visual pattern measurably. In other trials, with different reactors, no effects may be produced. The faint stimuli evidently can be ignored.

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[106]See Chapter XIII, p. 296.

CHAPTER XIII

SPACE PERCEPTION

§1. Space perception and muscular activity.

Space is perceived through all the senses, but by all except kinesthesis, it is perceived by means of signs. Vision and touch, the other most important space perceiving senses, can primarily perceive only extensity or bigness. Stimulation of more receptors in the retina or the skin results, in the perception of more of the sense data, in an extensity (not in intensity or durational) sense. Stimulation of different receptors gives perception of *different* sense data, but not primarily of the space difference. There is no conceivable way in which the perception of space could be built up except through muscular activity and resulting kinesthesis: and an inherited capacity to perceive space visually or tactually is due to the inheritance of reaction to signs, such as might be built up otherwise through experience.

Suppose that, vision being excluded, two spots on the skin of the arm are stimulated successively. If no tactual space signs have been built up, or inherited, these are felt as *different* touches, but not as in different places; and stimulation of a large number of spots gives no perception of distance or direction of these spots with reference to each other. But, if these spots are stimulated successively by moving the finger from one to the other: or if they are stimulated successively by some external object, through movements of the arm which bring the different spots successively in contact with the object, the tactual pattern becomes associated with the movements and the amount of movement, and so is woven gradually into a space pattern, in which distance and direction in space are involved. Distance and direction are not kinesthetic sentienda themselves, but are *relations,* which, first experienced between kinesthetic sentienda, are subsequently experienced between the tactual sentienda. A given tactual sentiendum, such as may be obtained from a certain spot on the skin, then becomes perceptible with space relation to other

points on the skin, and so is perceived as on a definite part of the body. In some cases, the tactual datum is merely the sign of a position in space.

The several positions of external objects in space, that is, their distances and directions from other objects, are perceived in the same way. A touch on the finger tip, followed by a touch on the same spot, with a definite arm movement entering, is the basis for the perception of the distance and direction of the second object from the first, assuming that the objects are not moving. The exclusion of motion of the object is achieved by repeating the exercises, and discovering whether the same amount and kind of movement is required for each trial. If under artificial conditions, an object is made to move from the one point to the other in the plane of the arm movement, an illusion of two objects instead of one is created, but the spatial positions may be correctly perceived nevertheless.

The perception of extensities of data as spatial depends on the discrimination, within the area stimulated, of smaller areas, so located that a movement is required to stimulate first one and then another by the same object. This explains why spatial discrimination is more acute on those parts of the body, such as the finger tips, on which variation in locus of stimulation, by small movements, is most frequently procured. The discrimination of two points as two on the arm is apt to be less accurate than on the finger tips; but the accuracy of discrimination on the arm may be greatly increased by practice, in which parts close together are successively stimulated by movements of the other hand holding a pointed instrument. Without the possibility of *exploration* of area in this way, by muscular activity, extensities in the skin would never have become spatial at all, but would be, like the extensities of audition (pitches), merely non-spatial characteristics.

Similar considerations apply to vision. By movements of the eyes, and by movements of the hands and fingers, or by moving small objects held in the hand, the various stimuli can be brought upon different retinal receptor groups, and thus the space relations of the movements are associated with the receptorial posi-

tions. In this way the perception of lateral distance and direction has been built up.

The dependence of visual space upon muscular activity has been strikingly shown by experiments in which lenses worn in front of the eyes re-invert the field of vision. In normal vision, since the rays of light cross in the eye, the picture on the retina, which is the actual stimulus pattern, is inverted and reversed right and left. If you are looking at a man standing erect, in the image on your retina the man is "standing on his head," *i. e.*, the head is down, the feet up; and the image of his hand at your right is on the left side of the retinal image. Yet you see the man as upright, and in actual position as regards right and left. This has seemed to some theorists difficult of explanation, yet it is quite intelligible as a function of muscular activity, in the light of the experiments of Stratton which we have just described.

In these experiments, the reactor wore the lens combination for a number of days, removing it at night only, so that his vision, during the period of the experiment, was always with retinal images re-inverted in positions exactly opposite to those of normal vision. At first consequently space relations were seen reversed. An object really at the right was seen at the left, and vice versa, and all objects were seen inverted. Attempting to touch an object resulted first in a movement in the wrong direction. In the course of days, however, the muscular activity set up new associations of retinal sign and space, so that the field of vision began to resume its normal position, and manipulation of objects approached normal. On final removal of the lenses the field of vision was confused, and required further time for readjustment to "normal" conditions of stimulation. It is obvious that vision alone gives no space relation, but that with any fixed correspondence of visual sign with external space, perception of the space relation may be built up.

Another illustration of the building up of the space perception habit may be obtained by putting a prism in front of one eye, keeping the other closed; or still better, by putting prisms in front of both eyes, the prisms having the bases in the same direction. Objects are then seen displaced, in the direction opposite the bases of the prism: if the prisms are placed with bases to the

right, an object is seen at the left of its true position. The visual pattern of the object, and the muscular pattern of the eye and head position, taken together, stimulate a reaction which will bring the hand, for example, to the point in space at which the object would normally be in order to produce that stimulus pattern. On account of the bending of the light rays by the prism, the object is at a point to the right of that at which, without the prism, it would produce the pattern. Hence, in trying to touch the object, the hand will be moved too far to the left. Practice quickly modifies the reaction, however, and at the end of a few minutes of muscular exploration of the field of vision, objects are seen "in their proper places:" that is, the new stimulus patterns produce exactly the same reactions which the corresponding patterns, without the prism, produced. A more conventional and less explanatory statement is that, new associations between the visual signs and the space relations have been set up.

In all these cases it is obvious that the visual stimulation alone does not constitute the effective stimulus pattern. A fixed point in the visual field may stimulate almost any group of retinal receptors, according as the eyes are turned in their sockets; as the head is turned on the shoulders, and according to the position of the body itself. In a given position of the trunk, and varying positions of the head and eyes, the same movement of the hand is required to touch a given object. The reaction terminating in the movement may be stimulated by a great many different patterns, involving a great many different positions of retinal stimulation, but in each of which a given retinal position is combined with specific positions of the eyeballs and of the head. It is certain, therefore, that the total pattern of visual and muscular stimulation (including stimulation of neck and eye muscles), is effective in directing the movement. A visual stimulation alone cannot produce an effective movement, since many different retinal stimulations correspond to the same movement, and each visual stimulation corresponds to a large number of movements.

§2. Visual depth perception.

Perception of depth, or distance from the eye, depends upon still more complex conditions of stimulation, and in these cases the effective data or stimulation conditions are, to a large extent,

signs: that is, are not perceived themselves, when the space relations they "mean" are properly perceived.

Accurate reaction to a stimulus pattern, and therefore accurate perception, depends upon the occurrence of patterns which correspond to the facts perceived; and discrimination between two facts depends upon the existence of effectively different stimulus patterns for the facts discriminated. The differentiation in pattern corresponding to different distances of objects is due to several different peculiarities of retinal and muscular function, which may be briefly listed as: (1) Convergence, (2) Accommodation, (3) Parallax, (4) Binocular disparity, (5) Intervention, (6) Chiaroscura, (7) Linear perspective, (8) Angular perspective (9) Aerial perspective, (10) Foreshortening. These we will discuss in detail.

(1) *Convergence:* The two eyes normally work together as one organ. They are independently stimulated, but the reaction is the product of both, and although the stimulation is double, the object may be seen as single. This result is due to the existence of *corresponding points* on the retinae.

If the visual stimulus for a *point* source falls on the center of one fovea, and at a certain point approximately at the center of the other fovea, the point is seen as single. These two retinal points are corresponding points, and the reaction and perception obtained from either are in many respects the same as may be obtained from both together. If, however, the stimulation falls on one fovea as before, but is made to fall at a slightly different point on the other; which may be done experimentally by placing a prism before that eye, or pressing with the finger on the eyeball, the object is seen double. The stimuli are no longer on corresponding points.

For every point on the retina of one eye, there is a corresponding point on the retina of the other eye. This is the law of corresponding points. Normally, corresponding points are in the same relative anatomical position in each eye, although in some eyes there may be a deviation from this rule. In looking attentively at an object, the eyes tend to take the position which will bring the image of each point in the object, so far as possible, on corresponding points of the retinae. In general the details most

attentively observed are brought (or their retinal images are brought) on the fovea. Obviously, for objects at different distances, different positions of the two eyes will be required to bring a point in the object on corresponding points in the two retinae. This may be illustrated by a diagram, which the student should draw. In looking from a far object to a near object, when both are in the same line through a point midway between the observer's eyes, the eyes must move so that the corneae move towards each other. This movement is called *convergence,* and by extension the term is applied generally to the angular position of the eyes, with regard to each other. The movements of convergence, or the muscle stimuli patterns aroused by them, become parts of the total pattern effective in space perception. Objects seen with more convergence are seen as nearer than objects requiring less convergence because the reactor has uniformly found that less movement by the hands, or less locomotion, is required to reach the first object than is required to reach the second.

Convergence, and the doubling of objects due to stimulation of non-corresponding points, may be illustrated by holding a pencil about 18 inches before the eyes, with the point just below a mark on the wall, at several feet distance. If one converges the eyes on the pencil point, the mark on the wall may be seen double: if one converges on the mark, the pencil point is seen double. Ordinarily, these "double images" are not consciously seen, because they are signs of depth. It is important for our understanding of the function of signs, to note that with both eyes open, with an object doubled by too near or too far convergence, one cannot directly distinguish between the image of the right eye, and the image of the left. By closing and reopening one eye, one can discover that with too near convergence, (*i. e.,* convergence on the pencil point while observing the doubled mark on the wall) the images are *homonymously* doubled: that is, the right eye's image is seen to the right of the left eye's; and that with too far convergence, the images are *heteronymously* doubled: that is, the right eye's image is seen as if at the left of the left eye's. But with both eyes open, it is impossible to distinguish directly between homonymous and heteronymous images, although these are important signs of distance, the object homonymously doubled

always being beyond the convergence point, and the heteronymously doubled object being always nearer than the convergence point. Not only are these two sets of signs not distinguishable from each other as signs, in ordinary vision, but they are not even *seen:* that which is perceived is the distance or direction of which they are the signs.

(2) *Accommodation.* The eye, like a camera, must be focussed for different distances. Focussing, or *accommodation,* is accomplished by a change of shape (curvature) of the crystalline lens. The lens, in its supporting ligament or capsule, is flattened, when the eye is at rest, by the internal pressure of the eye. Contraction of the ciliary muscle relaxes the tension on the capsule, and allows the lens to increase its thickness by its elasticity. The action of the ciliary muscle is perceptible, through the stimulation of the afferent neurons terminating in it. At short range, a slight change in distance of the object inspected necessitates a change of accommodation. For distances of over six meters from the eye, accommodation changes are slight, and beyond twelve meters are practically negligible, the "resting" condition of the lens being the approximate adjustment for all distances over that. The muscular stimulations resulting from accommodation are, therefore, signs of distance only at comparatively short range.

Accommodation changes may be observed by a method similar to that described for convergence. The pencil point should be brought in line with a distant mark and one eye, the other eye being covered. Changing the fixation from the pencil point to the distant mark, or vice versa, entails muscular changes easily perceived after a little practice, and clearly localized within the eye balls. Movements of convergence of the covered eye will occur, in the change of accommodation, because convergence and accommodation are habitually integrated, a definite degree of accommodation and of convergence being required for each distance. In ordinary vision, it is difficult to distinguish clearly the activity of accommodation from that of convergence, since the two are normally associated. But in the exercise described, the seeing eye being in line with the two observed points, makes no convergence movement, convergence being accomplished by the covered eye

only. Hence the accommodation movements of the eye may be observed.

(3) *Parallax.* If you look at a wall or background of any kind holding the finger, or a pencil, at arm's length before the eyes and then move the head from side to side, the relative position of the finger on the background, or its projection on the background, changes as the head moves. The near object (finger) is apparently displaced in the direction opposite to that of the head movement; or the background is displaced in the direction of the head movement. The greater the distance between the finger and the background, the greater the apparent movement. This phenomenon of apparent relative movement of objects at different distances, when the eye shifts its position laterally, is *parallax.* The direction of the parallactic movement is a sign which indicates which object is nearer, which farther: and the apparent magnitude of the movement is a sign of the relative distances.

(4) *Binocular disparity.* The consideration of parallax suggests at once that the two eyes, being at different points, will not receive the same stimulus pattern from a field of vision in which there is actual depth. Looking at a wall, with a pencil held at arm's length before the eyes, open the eyes alternately, and you will notice that a sort of parallactic effect is obtained without head movement. The right eye will see the pencil at the left of a certain point on the wall: the left eye will see it at the right. This is closely connected with the homonymous and heteronymous doubling of images but is not the same thing. The result of this difference in point of view of the two eyes is *disparity* of the image on the two retinae. With convergence for a certain distance, not only is there doubling of images for objects at a less or greater distance, but the relative spacing of details in the two retinae is different, and the amount of a far object covered or hidden by a near object may differ.

The stereoscope takes advantage of the phenomenon of binocular disparity by presenting a separate picture to each eye. The pictures are originally taken by a camera with two lenses, so that they together represent a scene just as it would be seen by the two eyes, or perhaps with the binocular difference slightly exaggerated by placing the camera lenses a little farther apart than

the normal interocular distance. These pictures are viewed through lenses, which are sometimes slightly prismatic in shape, so that the normal convergence for the apparent distance is permitted, and the two pictures blend into one view, in which depth effects are striking. The pictures can be combined, by a practical observer, without the lenses, but this is impossible for the untrained observer, since getting the pictures in the two eyes in corresponding positions requires, if no lenses are used, almost parallel direction of the eyes, with which is associated accommodation for a great distance, instead of the short distance at which the pictures are seen.[107]

Another device for making use of binocular disparity in reproducing depth effects is the *anaglyph*. In this device, the pictures, taken originally with a stereoscopic camera, are printed superposed, or rather, with a certain detail in each superposed, the degree of superposition for other parts of the view varying with their depth from the superposed detail. The pictures are printed in complementary colors, *e. g.*, red and green, and the observer is provided with spectacles in which one glass (or gelatin film) is red, and the other green. The glass before the right eye must be of the color in which the picture intended for the right eye (taken with the right lens of the camera) is printed, the glass before the left eye of the color of the picture for that eye. Since the red picture cannot be seen through the green glass, and vice versa, each eye sees its proper picture, and the combination gives depth as in the stereoscope.

Various attempts, mostly foolish, have been made to introduce binocular disparity into the movies. It might be done by the anaglyph method by superposing a right eye and left eye picture in complementary colors on the screen, and giving each spectator a pair of spectacles of the same color. In addition to the expensiveness of such a plan, so much would be lost in definiteness and illumination, and in the comfort of the spectators, that there would be a decided lessening of the effectiveness of the picture. The stereoscopic principle could be applied by projecting right-eye and left-eye pictures side by side from a double film, or from two

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[107]In looking at a single picture, a better effect of depth is obtained by using one eye only, because of the lack of binocular disparity when both eyes are used.

synchronized films: fixing at each seat a binocular telescope through which the spectator would view the pair: but this would be still more expensive, and the gain through depth would not offset the other losses in the picture.

A number of attempts have been made by projecting right and left eye pictures alternately on the screen. These attempts are due to ignorance of the principle of binocular disparity. In order to succeed, a double shutter before the eyes of each spectator would be needed, to expose the eyes alternately, in perfect synchronization with the film exposures, so that the right eye would see the right-eye picture only; the left eye, the left-eye picture only. Without the shutters, the alternation merely produces messy pictures, unpleasantly blurred, or with a disagreeable motion effect.

The four signs of depth so far discussed cannot be simulated in ordinary pictures. The first and fourth are also binocular: they require the combined function of the two eyes. The signs yet to be described are all monocular, that is, they apply to one eye as well as to two: and they can be simulated or represented on a single flat surface, as in a picture or on a movie screen.

(5) *Intervention.* In discussing binocular disparity we noted that one of the two stereoscopic pictures may show a far object less covered by a near object than the other. In a single picture, the mere partial covering of one object by another is a sign that the partially covered object is farther away than the covering one. If two men are seen, or are represented in a picture, both facing the spectator, with the outline of one completely shown, and only part of the outline of the other shown, the figure of the second man terminating at the outline of the first, the first is seen as in front of the second, although there may be no other sign of difference in depth, and although, in a picture, they are both painted on the same plane. A number of such interventions may be introduced into a picture, the first dog or tree or man partly occluding the second: the second partly occluding the third, and so on, thus giving "depth" to a scene which otherwise would appear "flat."

(6) *Chiaroscuro,* or the distribution of bright lights and shadows in an actual scene is dependent on the depth relation,

and the direction of illumination. Crags, projecting from canyon walls, cast shadows to the left, if the sun is on the right: to the right, if the sun is on the left. But the fact that they cast shadows at all is partial evidence that they project from the wall. More signs are needed, however, since caves or holes in the wall, of suitable shape, could appear as the same sorts of shadows, if the light were from the opposite direction. The decisive factor in this case, therefore, will be the high lights or areas of bright

Fig. 19.—Shadows as signs of depth. The design may be seen either as a cameo illuminated from the right, or as an intaglio illuminated from the left. The stronger tendency is to see it in relief, because cameos are more frequently seen than are intaglios. There is in this figure nothing except the shadows to give it either appearance.

illumination. In some cases it is impossible to tell whether a certain shadow is in a depression, or is cast by a projection. A mistake or false assumption as to the direction of illumination may produce a serious error. A bas relief, lighted from the side by a concealed source, may be mistaken for a cameo, if the direction from which the light comes is mistaken.

(7) *Linear perspective.* The retinal image of an object varies

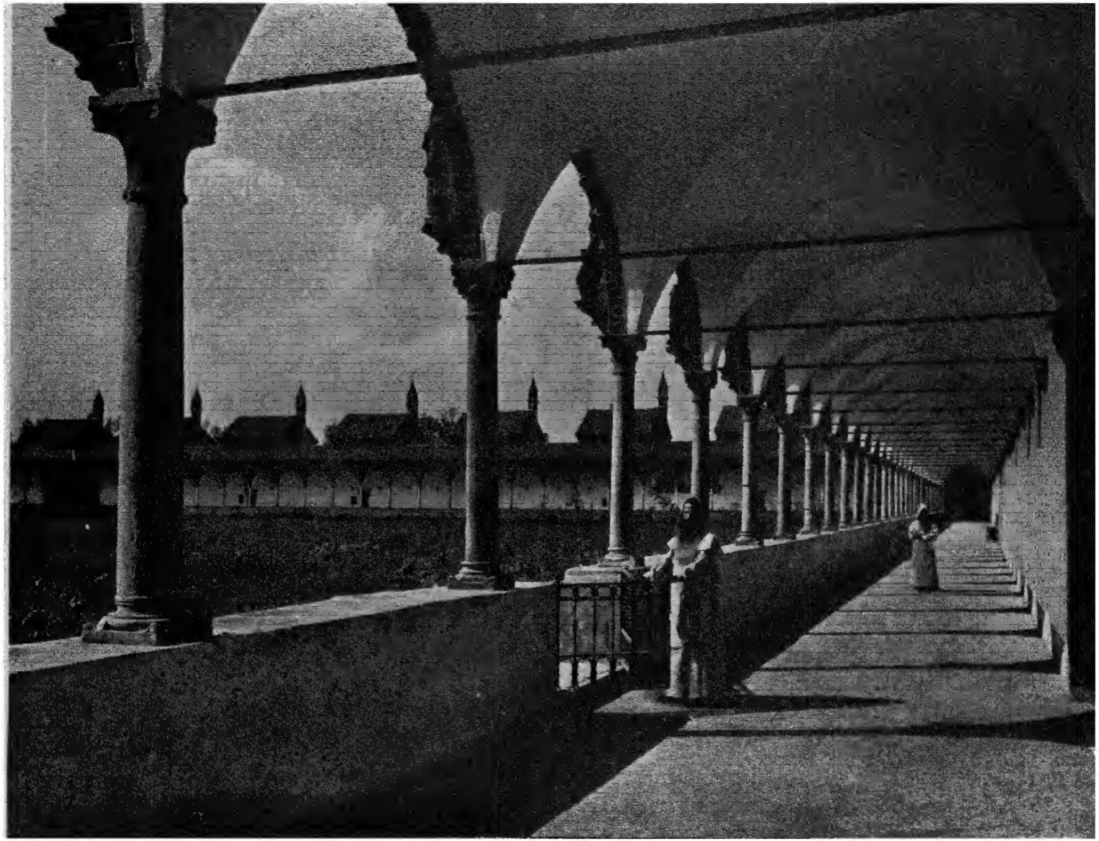

Fig. 20.—Linear perspective. The decreasing size of the pillars, and width of the corridor, and the difference of height between the two monks are efficacious in giving depth to the picture. The lack of other factors, such as intervention, causes the perspective to fail somewhat as regards the row of pillars in the background.

in size inversely as the distance of an object from the eye. An ink bottle at twenty feet from the eye has a retinal image just half the diameter of the same object at ten feet. The difference in size of the retinal pattern may give rise to perception of different sized objects, or to a perception of objects at different distances, since a mere difference in the size of the image could correspond to either of these spatial differences. In any case, some other sign must cooperate. If there is some sign which tends to produce the perception of equal distances, the sizes are perceived as proportionate to the image sizes. If, however, there is a sign which indicates equal size, the distances are perceived as merely proportional to the image diameters. Men, for example, are assumed to be of approximately the same height, unless some special indication of shortness or tallness is evident. Hence, varying sizes of images are signs of varying distances. The width of a road, or of a long corridor, is assumed as constant. To represent such a road or corridor on a plane, as in a picture, the width of the road or corridor, as depicted, must decrease to mean increasing distance, because this is the retinal condition in actually viewing such a scene. This correspondence between increasing distance of object and decreasing size of retinal image is conventionally called *Linear Perspective.*

(8) *Angular perspective.* An angle formed by two lines forms an image of a varying angle on the retina, according to the direction from which the angle is viewed. A right angle, for example, such as that formed by the edges of a table top, may have a retinal image varying from 180° to 0°, according to the direction from which the table is viewed. The image of the table top varies from a rectangle to straight line, through various rhomboidal shapes. The depth of the table, relative to the eye, is perceived in large part in accordance with the sign. If seen as a rectangle, both ends of the table must be equally distant from the eye: if seen as a rhomboid, one edge is farther away than another, and the more the rhomboid deviates from a rectangle, the greater the relative difference in depth.

Angular perspective and linear perspective are equally important in drawings, giving definite depth impressions if the natural

conditions are observed, and destroying depth effects if not in accordance with actual space conditions.

(9) *Foreshortening.* When a table top is viewed from a position opposite the middle of one end, and slightly above, the image of the table shows linear perspective; the farther edge of the table being shorter than the near edge: it shows angular perspective; the two nearer angles being less than 90°, the two farther angles being greater than 90°: and it also shows *foreshortening;*

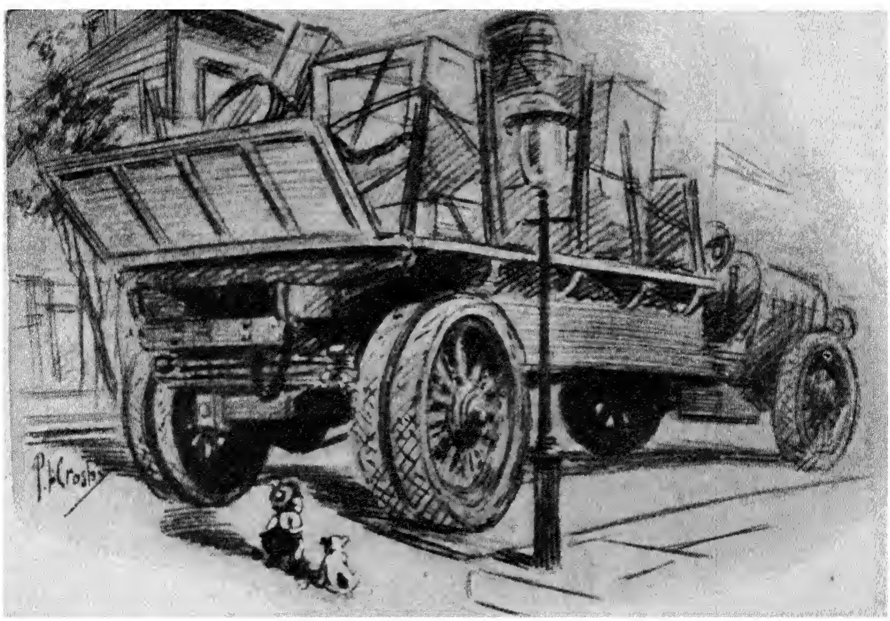

Fig. 21.—Angular perspective, foreshortening and intervention. (Copyright, 1921, Life Publishing Company. Republished by permission.)

the length of the sides being shortened in proportion as the line of vision (line of regard) approaches the plane of the table top. The maximal length of these lines in the retinal image, for a given distance of the table from the eye, is obtained when the line of vision is perpendicular to the table top: the length approaching zero as the eye approaches the plane of the table.

Foreshortening, as a sign of depth, depends, therefore, on other cooperating factors which indicate the relative length of the foreshortened line, as compared with other linear distances in the

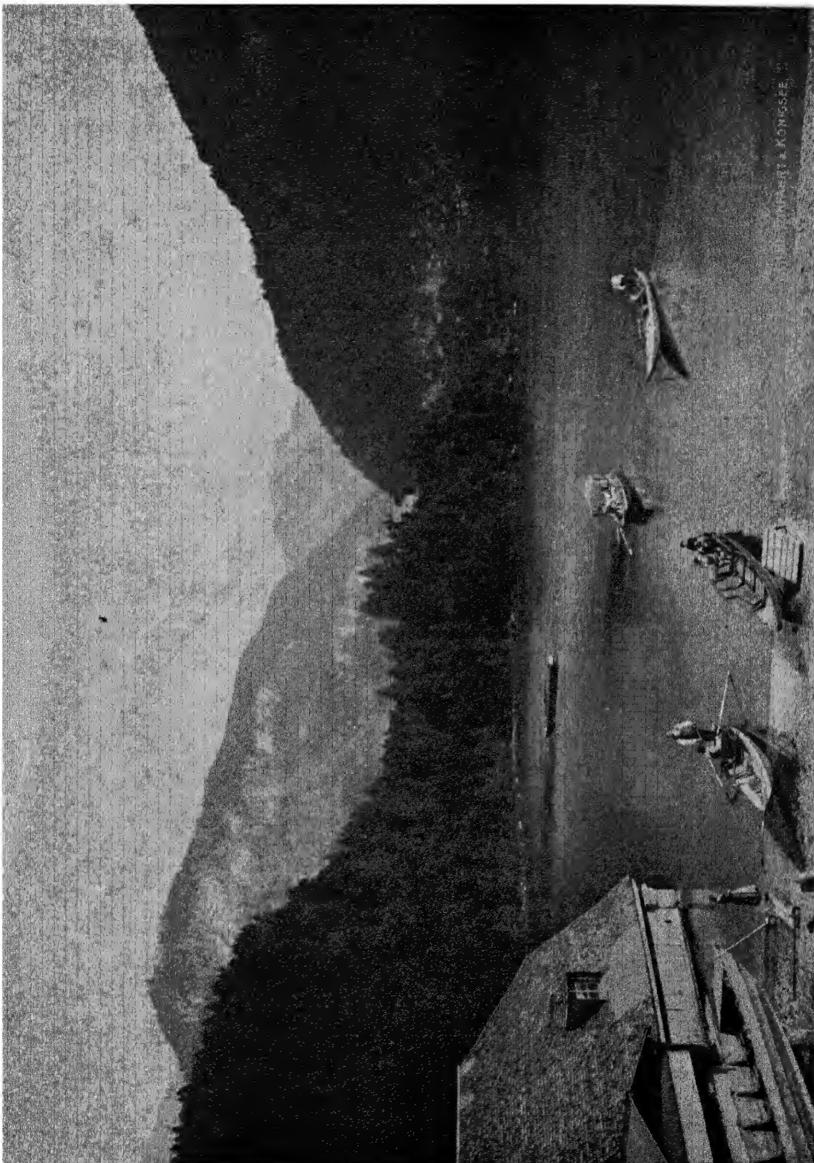

Fig. 22.—Aerial perspective. (To be compared with Fig. 23.) The obscurity of the farthest mountain makes it seem far away. Actually, it is not over six miles from the beach in the foreground.

Fig. 23.—Aerial perspective. (To be compared with Fig. 22.) The sharpness of outline of the mountain in the central distance makes it seem near. Actually, it is over 11 miles from the near foreground.

scene, and also indicate the distance of some part of the line from the eye. Lines of widely different length may have the same visual images, if the directions for the lines are properly chosen, and, conversely, the same line, in different directions, has varying lengths in the visual image. In cases where no auxiliary signs are present, the depth relation perceived may be quite different from the actual depth relation.

(10) *Aerial perspective.* The atmosphere usually carries dust, and sometimes water particles and smoke, which distort, disperse, or selectively absorb the rays of light, so that the outlines of distant objects are blurred, and sometimes colored bluish or purplish. The more distant objects will be more blurred, and more colored; accordingly blurring of outline, and purple or bluish colors, are signs of distance. Painters make use of this fact, blurring and tinting the background, if intended to be seen at a considerable distance, and so giving the signs which would come from natural objects at such distance. In actual landscapes, illusory nearness of mountains is often produced when the air is unusually clear, and so the mountains are no more blurred and colored than much nearer objects would be under usual conditions.

§3. Non-symbolic factors in space perception.

The ten factors described above are *signs* in the technical sense of the term. In so far as these pattern details are perceived as such, the depth they ordinarily mean is not perceived, and conversely, when the signs are unperceived, their depth meaning is most effectively perceived. For example: if two men, at different distances from the observer, are perceived as of different sizes, in accordance with the actual sizes of the visual images the observer has of them, the distances of the men are not accurately perceived: and the relative distances are most accurately perceived when the men are perceived as of equal size (assuming that they are approximately of the same size). Similar considerations hold for all ten of the signs of visual depth.

Depth perception through signs is obviously not an inference: we do not (in usual cases) perceive the sign, and infer the distance or direction from it. We do not perceive the sign at all. It is a detail, or group of details, in the stimulus pattern which

immediately causes the total reaction through which we perceive objects in certain space relations. The depth and other space relations are perceived as integral parts of the total visual content.

Signs are not the only means of visual depth perception. Various details of the visual pattern may produce depth perception, as well as other sorts of space perception, while being perceived themselves, as part of the content. A face, seen full, against a uniform background, will be seen with the nose in relief and the eyes sunken, even when the lighting is such that no one of the ten signs of depth is present. Even the picture of a face, with none of the ten signs represented, may be seen as the picture of a *face,* and not as a flat diagram of a face. This is in accordance with the general principle of perception, as earlier described, by which the presentation of a part of the data of an object produces the reaction for the total object. A reaction to a face, including its space relations, has been built up through muscular exploration, and hence the presentation of certain characteristic features of a face will produce the perceptual reaction for a face. In less technical language: the space relations of a face have been "associated" with the visible outline and details, and are perceived when these are perceived.

§4. Auditory space perception.

The only space relations of auditory data in themselves are the relations of pitch and timber, and these are not analyzed because there is no muscular mechanism by which the pitch and timber of tones can be varied. Sounds, therefore, function in space perception only as signs or as associations of distance and direction of the sources of the sound. The sound of a violin is not heard as spatial, but is heard as coming *from* a violin at a certain distance, in a certain direction. The auditory pattern varies according to the distance or direction of the source, in pitch, timber and intensity.

The pitch of the sound from a certain source is higher when the source is moving towards the ear, and lower when the source is moving away from the ear. This may most easily be noticed by comparing the pitch of a locomotive whistle when the train is rapidly approaching, with the pitch when the train is passing.

Since sound waves travel through the air at approximately 1000 feet per second, the pitch of the note, when the source is approaching, will be the normal pitch of the note multiplied by 1000, divided by the speed of the train in feet per second. In ordinary life, perceptions based on these pitch changes are not built up, and the only awareness of motion due to such pitch changes is due to inferences from the observed changes.

The loudness (intensity) of a sound varies inversely as the square of the distance of the source. Hence, the nearer the source, the louder the sound, and if the normal loudness is known, an inference as to distance may be made. Since there is repeated experience of objects sounded at various distances, perceptions of different distances are built up, but only with rough accuracy. A faintly sounding violin or human voice is experienced as at a greater distance than a loudly sounding violin or voice. Since the same loudness can actually come from different distances, according to the absolute sounding of the instrument, such perceptions are subject to grave error.

The relative loudness of sounds in the two ears varies with the direction of the sound with respect to the head. If the sound comes from the right, the right ear is more strongly stimulated than the left, on account of the "sound shadow" cast by the head.[108] If the sound comes from the left, the left ear is relatively more stimulated. Hence, the general direction from which sound comes is readily perceived, the difference in intensity being an unperceived sign. The intensity gives no sign as regards the direction of forward and back, up and down, since from any points in the median plane, the intensity effect on the two ears is equal: hence, a sound directly in front of the observer may be heard as above, or behind, unless other signs or associations are present. Variation in the position of the sound from the position directly opposite one ear towards the medial plane varies the relative intensities in the two ears; but variations forward, back, up and down produce the same effects, and hence it is impossible, by the intensity signs alone, to distinguish sounds coming from positions diagonally upward, downward, back, or forward. For example:

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[108]Interference of waves transmitted through the head from one ear to the other may also affect the relative intensity in the two ears.

the position of a source of a pure tone directly opposite one ear is correctly perceived; the position of such a source 10 degrees forward from this point is perceived correctly as far as its angle is concerned, but it may be perceived as 10 degrees up, down or back, instead of forward.

The fact that the intensity differences in the two ears are only signs, and are not perceived themselves, may be demonstrated by employing two sources, of the same pitch and timber, one opposite each ear of a blindfolded reactor. Two telephone receivers, actuated by a common current, are adequate. The reactor hears only one sound, and if the sources are made of unequal intensity, the sound is heard as coming from a source on the side of the higher intensity. By finding the relative intensities of the two sounds which cause the reactor to localize the sound in his median plane, the relative sensitivity of his two ears may be noted.

Discrimination of positions forward, back, up and down, are possible in audition only through timber signs. The concha of the ear selectively modifies the partial tones in a complex note so that the timber is not quite the same in these different positions of the source. Obviously, perception based on this sign is possible only when the sound employed is a complex and familiar one. In case of a pure tone, such localization is impossible.

On the whole, auditory space perception is vague and inaccurate. Most of our localizations of sources of sound are based, not on auditory, but on visual or other signs of associations. Even the binaural signs may be inefficacious when visual associations are against them. If a violin is silently bowed at the reactor's right, in his field of vision, and a concealed violin is actually sounded on the reactor's left, he will perceive the sound as coming from the wrong direction, in spite of the fact that the binaural sign of relatively higher intensity in the left ear is present. The success of the ventriloquist is largely due to this sort of overcoming of auditory conditions by visual ones. Such control of the voice as the ventriloquist uses is confined to changes in timber, which make the voice unnatural in sound. Since the tones do not sound like those ordinarily coming from a human throat, we are more easily disposed to perceive them as coming from the

object from which the ventriloquist, by visual cues, or verbal description, makes us perceive them to come.

§5. Space perception through other senses.

Although odors are conveyed to the nasal receptors from distant objects, there is no olfactory perception of direction, and little of distance. There are neither signs nor associations of direction in olfactory perception, since the air-dissolved odorous particles must enter the nostrils in the same way, and make the same impression on the receptors, whatever the direction from which they come to the external nares. There is no muscular mechanism which varies the adjustment of the olfactory apparatus for either distance or direction. The perception of direction of an odorous object is always tactual, thermal, auditory, or visual, or a combination of these. An odor of honeysuckle, when the wind is from the left, may cause the perception of "honeysuckle at the left:" but the signs are the tactual or thermal stimulations, the breeze, or the visible movement of smoke, leaves, or other indications of air currents. If the honeysuckle is smelled, and also seen, the localization of the source of odor is visual. If we experience the characteristic odor of a wet dog in a dark room, the source cannot be localized until one touches the dog, or hears him.

The relative intensity of an odor may be a sign of distance. The odor of any given source, at a given time, and in a given direction, is stronger when the object is near, and weaker when it is farther away. Hence, there are roughly valid olfactory perceptions of distance. No great accuracy is possible, however, since the odors of most sources vary from time to time, and the direction of air currents and the temperature and moisture of the air cause large variations in the odor from a given object at a given distance. The odor of a bed of petunias, at a certain distance, may be faintly perceptible at one time, and may be strong at another.

The qualitative character of certain odors varies with the intensity of the total odor, the odor being characteristically different at different intensities. In this respect, these odors behave as if they were made up of a number of elementary odors, the

relative intensities of the elements not varying in the same measure, so that at one intensity, certain elements predominate, while at other intensities, other elements predominate. It may be that such changes, which occur with intensity change due to distance change, are changes in signs which might assist in the perception of distance.

Gustatory localization could, in any case, be no more then perceived position of stimulation on the tongue. How far such localization is possible has not been determined. In the usual cases of gustatory perception, tactual data are also present, and are the bases of localization. Gustatory extensities are discriminable, according to the area stimulated on the tongue. No distinctions of olfactory extensities have been noticed.

Organic sentienda have volume, or extensity, and are more or less accurately localized in the organism. Pains and aches, for example, may be "fine" or "sharp," or may be "massive," or extensive. Pains in the external muscles, and in the teeth and bones, are fairly well localized; and various cutaneous and subcutaneous sentienda: itches, pains, tickle, etc.: are localized approximately. Sense data for the viscera, however, are very vaguely localized. Many persons cannot distinctly perceive hunger as in the region of the stomach, and for some the fullness of the bladder is referred to the abdomen generally. These facts agree with the general principle that exploratory muscular activity is necessary in order to learn to perceive space location, and where such exploration is not fully possible, as is the case with the viscera, localization is imperfect. By movements of the trunk muscles, certain grossly defined variations in pressure on the viscera are possible, and hence a certain perception of space is built up. Pressure in the bladder is localized in the abdomen, because pressure on the abdomen from outside, or exercised by the diaphragm or by the abdominal muscles, modifies the bladder pressure; and fine localization is impossible, because no fine exploratory movements are possible.

Certain painful feelings which are really in the viscera are perceived as located in areas of the skin. These feelings are "soreness" or "tenderness" due to diseased conditions of the viscera, and are known as "referred pains." Pains from specific

portions of the alimentary canal and other visceral organs are referred to specific areas of the skin, and these "areas of referred pain" have been carefully mapped by Head and others. The "referring" of pain in this way is apparently due to a synaptic connection between the afferent neural route from the skin and the afferent route from the viscera established somewhere along the line, perhaps in the spinal ganglia or spinal cord, so that current coming from the viscera reaches the cerebrum by routes over which current normally comes from the skin. The fact that the reference occurs, indicates that the transference of current is not normal, but is due to pathological conditions, for which no space perception system has been built up by normal life. The false localization would undoubtedly disappear in the course of time, but slowly, since muscular means for the quick referring of visceral space perception are not at hand.

§6. The perception of movement.

The perception of movement is closely related to the perception of space in two ways. In the first place, it is the original basis of all our space perception, and, in the second place, movement includes space as well as time.

Movement of a part of the body in many cases functions as a sign, and not as an associate of spatial factors in perceived objects. That is, we perceive the space relation, but not the movements which are essential to the perception. This is the case, for example, with convergence movements of the eyes, and in other instances where movement functions as a highly developed perceptual reaction. In the building up of these reactions, however, movements function as associates: that is, as perceived details upon which the indirectly perceived content depends. The relegation of associates to the position of signs, that is: from the conscious to the non-conscious level, is but one case of the general course of reactions, which tend wholly, or in part, to become unconscious in so far as they are completely perfected, the conscious factor being apparently important during the learning process, or where the reactions must be held constantly subject to modification.

In many cases we find that movement of a body-part functions

as an associate, and not as a sign. If, for example, you are blindfolded, and asked to compare the length of two sticks by "feeling" them, *i. e.*: by moving the finger tips along them; the movements are perceived as movements, and at the same time are the basis for the space perceptions: they are part of the direct content in the total perception, in which the space relations are the indirect content.

Movements of parts of the body with reference to the total organism, are perceived through muscle receptors, tendon receptors, and joint receptors. In active movements, muscular contraction and relaxation occur; the pressure and tension changes in muscles and tendons stimulate the receptors terminating there; and the movement of joint surfaces over each other stimulates receptors terminating in the joint capsule and the cartilaginous surface of the joint.

In movements of the head, in addition to the effects in neck and shoulder muscles, and the vertebral articulations, the receptors terminating in the semicircular canals are stimulated. Although the stimulation of the receptors in ordinary movements does not contribute directly to the perception of movement, that is, there are no sentienda connected with the stimulation of these receptors, it modifies the perception indirectly, since the reflex discharges initiated in these receptors modify the ensuing muscular activity, and hence modify the perceptions. The mechanisms in the ampullae of the semicircular canals are not sense organs for motion: they are really receptor-organs for unconscious reactions affecting the muscular system in such ways as to assist in the coordination of movements, especially the movements of the eyes.

Movements of the body as a whole, either rotation or translation, are perceptible without the aid of vision, but only during, and for a short time after, acceleration or retardation. If a reactor, blindfolded, is seated in a rotation chair, and the chair set in rotation, continuing thereafter to rotate steadily, without further acceleration or retardation, the reactor perceives the commencing of the rotation, and perceives himself as continuing to rotate for a brief time, usually from ten to fifty seconds, depending upon the reactor, and the rate and amount of acceleration

Then, if the rotation is quite steady, he seems to come to rest, and to remain at rest as long as the rotation is steady. If the rotation be then stopped, the reactor feels himself stopping, and then for a number of seconds, rotating in the opposite direction, although really at rest.

The acceleration stimulates the organism in various ways. The inertia of the body, if the reactor is supported only by the chair seat, causes a twisting of the body, which stimulates various kinesthetic receptors. The inertia also exerts a lateral strain in the skin and subcutaneous tissues of the buttocks and legs. The inertia of the viscera also causes changes in internal pressure, of the viscera against the thoracic and abdominal walls, and of the viscera against each other, and change in tenseness of the mesenteries. All these are efficacious in initiating the perception of rotation, and function as long as the acceleration continues, and while the normal tensions and pressures are being restored. When a reactor is set in rotation at a rate of one turn in two seconds, with acceleration from rest to full velocity in two turns, the visceral stimulation has been demonstrated to be a powerful one, from which alone definite perception of rotation would arise.

In the process of acceleration, the semicircular canal receptors are stimulated. While this does not in itself give rise to a perception of rotation, it produces certain important muscular effects, chief among which are: (1) Increased tension of the muscles in resisting the torsion of the body above described: the torsion resulting from the movement impressed on the hips by the chair, and the inertia of the trunk and limbs. (3) Relatively increased tension of the recti muscles of the eyes, on the side opposite the direction of rotation, causing the eyes to be turned in that direction; that is, to lag behind. The lagging sets up a reflex which jerks the eyes ahead, and the lagging commences again. This alternate lagging, or drifting of the eyes in one direction, with the recovery or jerking in the opposite direction, is called *nystagmus.* These muscular effects of simicircular canal stimulation undoubtedly affect the perception of rotation: but their most characteristic results are produced after acceleration has ceased, that is, after the rotation has reached a constant speed. The nystagmus, and undoubtedly the other muscular effects, persist after the

acceleration, which is the only stimulus, has ceased, and are the causes of the prolongation of the perception of rotation. This is evident from the fact that the perception of rotation normally ceases when the nystagmus ceases. If we wait until the effects

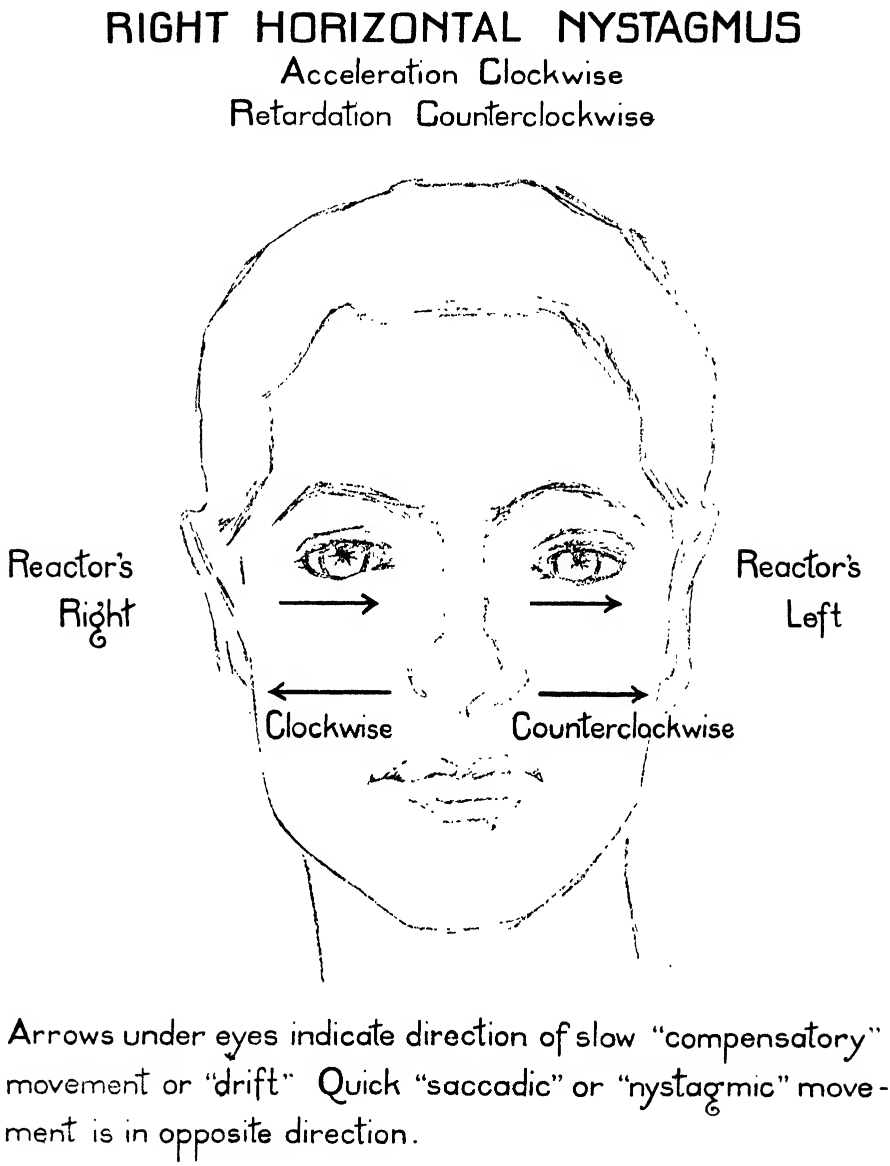

Fig. 24.—Direction of eye movements in horizontal nystagmus.

of the stimulation of the simicircular canal receptors have worn off (the stimulus itself having ceased with, or shortly after, the end of the acceleration) and then stop the rotation, similar effects are produced, but in a reversed direction. The eyes drift in the direction of the preceding rotation, and are jerked back: and the body torsions, and tensions or lurch in limb muscles are the reverse of those found during and immediately following acceleration. The reactor has the "illusion of rotation" in the opposite direction, which, in the normal subject, lasts exactly as long as the nystagmus does. If the rate of retardation in stopping is exactly the same as the rate of acceleration in starting, the nystagmus and illusion of rotation in the one case lasts exactly as long as the nystagmus and perception of movement in the other: provided, of course, that the rotation was continued long enough to allow the effects of the acceleration to disappear.

Such stimulation is pathological, of course. In normal living conditions, rotations are brief, of relatively few degrees, and the retardation stimulus occurs so soon after the acceleration stimulus that the one practically cancels the other, and hence there are negligible after-effects. The condition of long continued rotation is one to which the organism has had no chance to adapt itself. Dancers and acrobats who practice long continued whirling or turning, gradually become adapted to the condition of stimulation, and lose the nystagmic and other objectionable effects. By brief periods of daily rotation in a chair, a normal subject will, in a few weeks, completely lose the nystagmic and other muscular effects of excessive semicircular canal stimulation, while retaining full normal reaction to normal rotary stimulation.

In addition to the effects of labyrinthine stimulation on the striped muscles, there are effects on the stomach muscles and probably on other smooth muscles; and there is also an effect to which the terms *dizziness* and *vertigo* are sometimes applied. Since these terms also apply to the illusion of rotation following rotation, a new term ought to be applied to the sentiendum or sense complex in question, which is quite distinct from the illusion of movement. The illusion of movement, conversely, often occurs without this sort of "dizziness."

The effect on the stomach muscles is apparent as *nausea,* and when violent, as retching movements. Even when no distinct nausea is produced, changes in the normal stomach contractions are produced.

In movements of translation of the body, that is: in motion on a straight line, the semicircular canals are apparently not stimulated. The receptors in the vestibule of the ear may, however, be stimulated, and visceral, cutaneous and somatic stimulations occur under the influence of inertia, giving rise to the perception of motion. In this case, however, the perception of movement ceases very shortly after acceleration ceases (provided that visual and auditory signs are excluded). The phenomena are most easily studied in an elevator, in which the visceral sense data, the tactual change in the soles of the feet, and the effects on the joints of the legs are readily brought under observation.

§7. Equilibration.

The maintainance of balance, as regards the force of gravity, is the result of reactions or modifications of reactions originating in the receptors of vision, the dermal and kinesthetic receptors, and the receptors of the vestibule of the ear. The importance of visual signs can be demonstrated by blindfolding a reactor, and causing him to stand upon a platform which can be tilted in various directions: the deck of a rolling ship, for example. In such a condition, equilibration is more difficult, and less successful than with the eyes open. Even in standing on a solid floor, the reactor cannot stand so nearly still when blindfolded as with his eyes open. The functions of dermal and kinesthetic factors can be readily observed by the blindfolded reactor himself when on an unstable platform.

The vestibular mechanism has an important function on eqilibration, through its effects on the striped muscles. If one starts to fall in a given direction, the stimulation of the vestibular receptors seems to produce by reflexes increased tension on the muscles on the other side, facilitating the movements of recovery of balance. Whether the semicircular canal mechanism has any function in equilibration, is uncertain.

§8. Visual anesthesia and perception.

The eyes perform movements of two types, already described in the discussion of nystagmus. One type of movement is the drifting movement, characteristic of the observation of a steadily moving object, and of the slow movement in nystagmus. If you watch a white spot on a slowly revolving disc, or watch the bob of a slowly swinging pendulum, the eyes move so that for a considerable part of the path of the moving object, the image remains practically on the same portion of the retina, and is continually seen. The other type of movement is characteristic of voluntary shifting of the eyes. If you look at an object directly in front of you, and then look at an object at the right or left, the eyes execute a quick movement from the first position to the second. The quick or "recovery" movement in nystagmus is of this type, and although not strictly voluntary, it is often designated as such. In order to avoid confusion, eye movements of this type are now called *saccadic.*

During the greater part of a saccadic eye movement, the eye is blind. This has been experimentally proved, and might be inferred from a variety of visual phenomena. This blindness prevents the blurring of the visual field, as the eyes are moved from point to point. If you keep the eyes fixed, and move an object in front of them, its outlines blur. A common illustration of this is obtained at night by waving a stick on the end of which a live coal has been fixed. The image of the coal is drawn out into a line of fire. But, if the coal is held at rest, and the eyes moved from point to point voluntarily, no such effect is produced. Occasionally the drifting movement of the eye can be obtained under such circumstances, and then a streak of light is seen: but this is an exceptional occurrence.

If it were not for the anopsia during saccadic movements, the blurring of the field of vision in glancing here and there very probably would be not only disagreeable but disturbing to the efficiency of vision. In reading, the eye executes a series of saccadic movements from point to point on the printed line, and from the end of one line to the beginning of the next. One can easily imagine the confusion which would occur if the words were visible during these movements.

The conditions of vision during saccadic eye movement of vertical and rotary types are at present obscure. We cannot say that there is regularly, if ever, anopsia during either of these types of saccadic movement. The results of observations during rotary nystagmus bear on this point.

In horizontal nystagmus, which is readily obtained by rotating the reactor for some seconds about the normal vertical axis of the head, the intermittent anopsia produces illusion of movement of the visual field, if the eyes are open, in the direction of the saccadic movements. During the slow, or drifting movement of the horizontal nystagmus, the eye sees, and the movement of the images across the retina cause the illusory perception of movement of the objects seen. During the saccadic recovery movement, the eye is anopsic, hence there is no reversed illusory movement. If the eye could see during both movements, there would be slow apparent movement of the field in one direction, alternating with rapid movement in the opposite direction.

In rotary nystagmus, which may be obtained by rotating the reactor, seated, with head bent forward so that the normal vertical axis of the head is horizontal, the eye is rotated on its dorsiventral axis by the action of the oblique muscles. The rotations are alternately of the slow or drift type, in one direction, and the quick or saccadic in the opposite direction. If the eyes are open, the visual field appears to rotate like a wheel, either in the direction of the slow or of the quick movement. Some reactors obtain the one illusion, others the other illusion, and some obtain both at different times. This would suggest that anopsia may occur during either type of rotary movement.

Since with the usual type of eye movements in observing a scene, or in reading, repeated moments of anopsia occur, it is obvious that although the objects are seen continuously, the afferent current from the eye is intermittent. Conversely, if the scene is presented intermittently, as on the movie screen, at a sufficiently rapid rate, it is seen as continuous. Even if the rate is so slow that flicker occurs, there will be apparent continuity. If an actually moving object is being observed, it can be clearly seen in one of two ways. First, the eye may "follow" the ob-

ject: that is, the eye may execute a drifting type of movement, at the same angular rate as that at which the object is moving, so that the image of the object is, for a fraction of a second at least, maintained at rest on the retina. This is the cause of the occasional distinct vision of the spokes of a rapidly turning wheel, which blur most of the time. If one casually observes the wheels of passing automobiles, one finds that the spokes at the top, or at the bottom, will "flash out" momentarily, according to the speed of the eye movement. Spokes are never seen at the top and bottom both; and since the top of the wheel is moving forward faster than the bottom, a more rapid drift movement is required to see the top spokes than is required to see the bottom spokes. If one observes a disc, rotated on a spindle, and having radial stripes or sectors of black and white, one finds that horizontal eye movement in one direction causes the stripes or sectors to appear at the lower part of the disc: eye movement in the other direction causing the stripes or sectors to appear on the upper part of the disc: because in this case the top and bottom of the disc are really moving in opposite directions.

If objects are moving in various directions in the field of vision, as is the case of a man moving about, clear vision can be obtained only by a series of saccadic movements, introducing momentary periods of anopsia, so that the visual mechanism is stimulated intermittently. In these cases the moving objects are really *presented* in a series of positions, not, in continuous movement, but are *seen* moving. This condition of stimulation is employed in the motion picture, the objects in action being presented in a series of positions, and hence seen as in motion, although the eye may be at rest. The intermittent nature of the stimulation in motion pictures may be clearly observed if the eye is allowed to drift, while a non-moving object (as the words of a title) is on the scene. Drifting of the eye brings the successive stimulations in different retinal areas, and therefore the words are seen multiplexly.

The so-called *stroboscopic phenomenon* is obtained when the eye is stimulated intermittently by a series of objects so nearly alike as to be indistinguishable. In the case of the striped or sectored disc, for example, if the stripes or sectors are uniform,

that is, the white stripes or sectors all alike and equally spaced, and hence the black stripes or sectors also alike and equally spaced, and if the disc be illuminated by intermittent light so timed that the period between successive illuminations is exactly that required for a given white stripe to move to the position of the next white stripe, the disc will be seen as at rest. If the disc, for example, has twenty white stripes on a black ground, and is rotated once per second, it must be illuminated by intermittent light of twenty flashes per second in order to seem at rest. If the period of the intermittent light is slightly greater, the disc will seem to rotate slowly in its true direction: if the period of intermittence is slightly less, the disc will seem to rotate slowly backward. This explains the curious effect sometimes observed in the movies, in which a rapidly moving automobile has its wheels apparently not turning, or turning very slowly in either direction.

An illusion of movement in which the observer of a moving object seems to move, and the actually moving object to be at rest, is often observed in railway stations. A train next to the one in which the observer is seated begins to move, but seems to be at rest, while the observer seems to move in the opposite direction. This illusion is due solely to eye movements. The moving of the train evokes repeated drifting movement of the eyes, with alternating saccadic recovery movements, exactly the sort of eye movements produced by watching a scene through which one is moving backwards. If the eye movements are inhibited, the illusion ceases: but the inhibition is sometimes very difficult. The same nystagmic movements which make an object at rest seem to move, make an object really moving in the opposite direction, at the same rate, seem at rest. The same sort of effect is produced when the observer is blindfolded, or in the dark, so that nothing is seen during nystagmus: the observer seems to rotate in the direction opposite to that in which objects, if seen, would appear to move.

§9. Spatial illusions.

Certain phenomena of space perception are commonly classed as spatial illusions, although the distinction between these phe-

nomena and the general phenomena of space perception is not sharp. Some of these illusions are easily explained on the fundamental principle of habit, and the others are undoubtedly explicable on the same basis. Many of them are named from the persons who first described them.

(a) *Aristotle's illusion.* If two adjacent fingers are crossed, far enough to form a distinct crotch, and an object, such as a pencil, pressed into the crotch, the eyes being closed, the object is perceived distinctly doubled. If the tip of the tongue is pressed

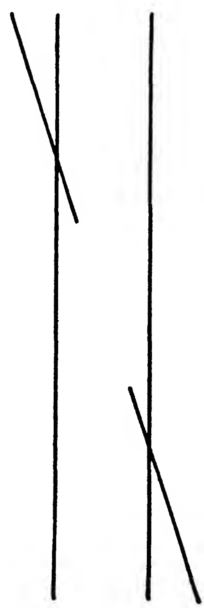

Fig. 25.—Poggendorf's figure. The two oblique lines are really segments of the same straight line.

in the crotch, the tongue is perceived as forked. This perception is obviously the habitual one for the stimulus, since the opposite sides of the fingers are stimulated, which is the accustomed stimulus of two different objects. The perception of two objects has been built up as a response to this stimulus pattern, and results in the habitual way. It is true that the total stimulus pattern is different in the two cases: in the normal case the fingers are side by side: in the illusion they are crossed. The crossed position is distinctly perceptible in itself, hence it is possible to build two different reactions on the same pattern: a reaction of perceiving

two objects from the tactual stimulation of the outer surface of the fingers when they are not crossed; and a reaction of perceiving one object when the same tactual stimulation occurs with fingers crossed. But the latter pattern of stimulation has occurred

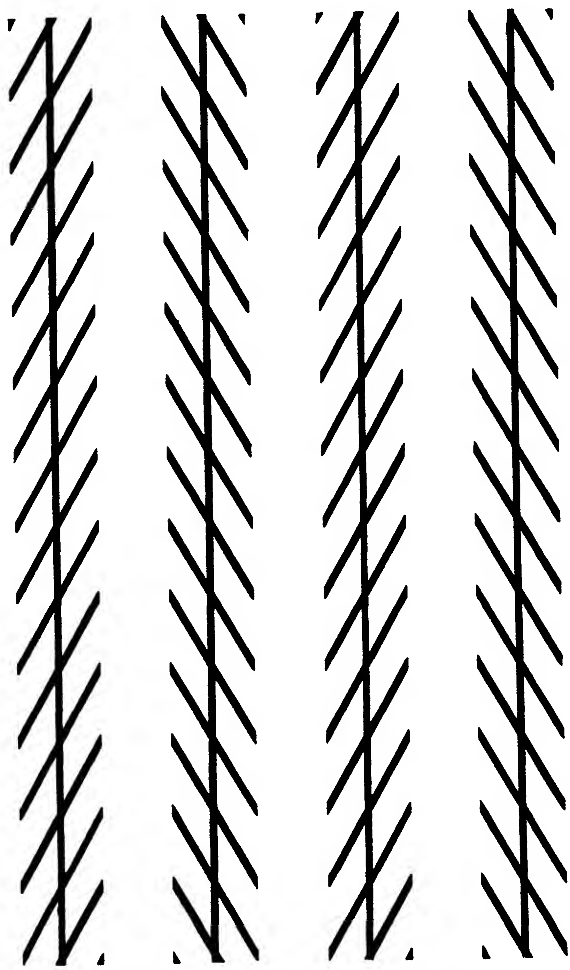

Fig. 26.—Zöllner's figure. The long lines are really parallel.

so seldom in the experience of most persons that the reaction has not been built up, and the important "fingers crossed" part of the pattern is simply "disregarded:" that is, like a purely adventitious detail of stimulation, it does not prevent the accustomed reaction from occurring.

(b) *Stratton's illusion.* A converse form of the Aristotle illusion may be obtained when the two fingers are crossed, by stimulating simultaneously the two skin areas, one on each finger, which are habitually stimulated by a single object between the finger in the normal position. This illusion can sometimes be obtained when the fingers are not crossed, but are widely separated. In general, such stimulation gives rise to the perception of a broad object, of width corresponding to the separation of the fingers.

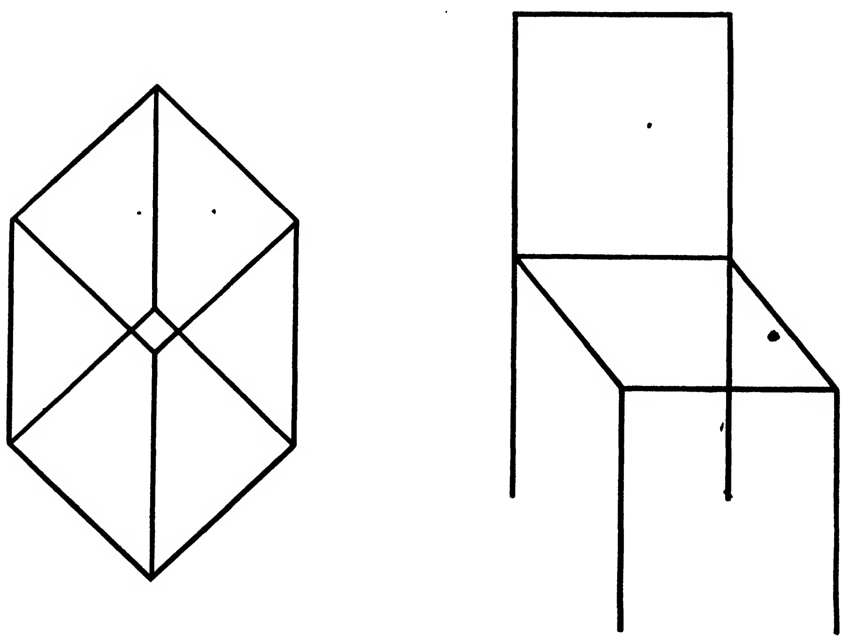

Fig. 27.—Reversible perspective figures. At any moment the chair may appear either as viewed from the front or the rear. The other design, "Necker's Cube", will appear likewise in either of two positions.

Stimulation by objects of different breadth between the fingers has been a common experience for most persons, and differentiated perceptions based on the total pattern of the tactual stimulation and the separation of the fingers (kinesthetic) have been built up.

(c) *Illusions of direction.* The Poggendorf figure (Fig. 25) and the Zöllner figure (Fig. 26) are typical illusion figures in which the relative direction of lines are distorted. In the Poggendorf figure, the two short lines, which are really on the same straight line, seem to be displaced, so that their prolongations

would be not common, but parallel. The effect is the same as that which would occur if the points of intersection of the diagonal lines with the vertical parallel lines were kept the same, and the acute angles were made slightly more obtuse, while the vertical lines remain parallel.

In the Zöllner figure, the long lines, really parallel, seem to converge. In this case, also, the effect is *as if* the acute angles were rendered more obtuse, but the effect is on the apparent positions of the long lines, and not the short ones. No satisfactory

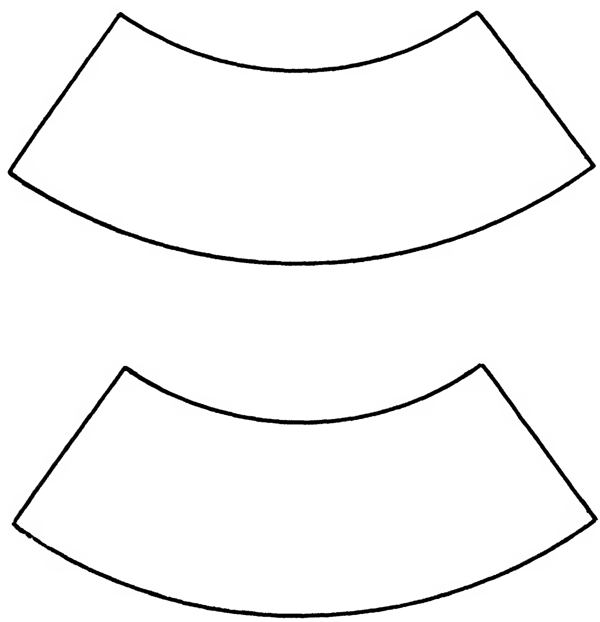

Fig. 28.—Jastrow's figure. The two outline figures are exactly alike.

explanation of the building up of these perceptions has yet been given, although many theories have been advanced.

(d) *Illusions of angular perspective.* Certain linear figures which constitute outlines of objects having depth, or difference in distance from the eye, may be so drawn as to be seen in either of two contrasting positions, the relatively nearer points in the one position being the farther in the other. Such figures (Fig. 27) must be so drawn that there is no true linear perspective, and so that angular perspective and foreshortening are either ab-

sent or equivocal: that is, are appropriate to both positions. In such cases, the stimulus-pattern is as near the habitual pattern for perception of the one position as the other.

Such reversible perspective figures usually present the striking phenomenon of fluctuation: on gazing steadily at the figure,

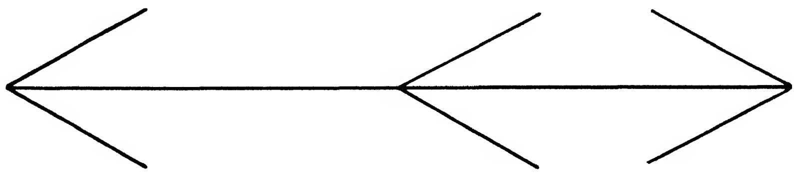

Fig. 29.—Müller-Lyer's figure. The long line is divided into halves by the vertex of the middle angle.

it appears for a time in one perspective, and then suddenly changes into the other. In some cases this change is due to ideational processes: to thinking about the other position. In other cases, the change occurs in an automatic way, with no preceding thought

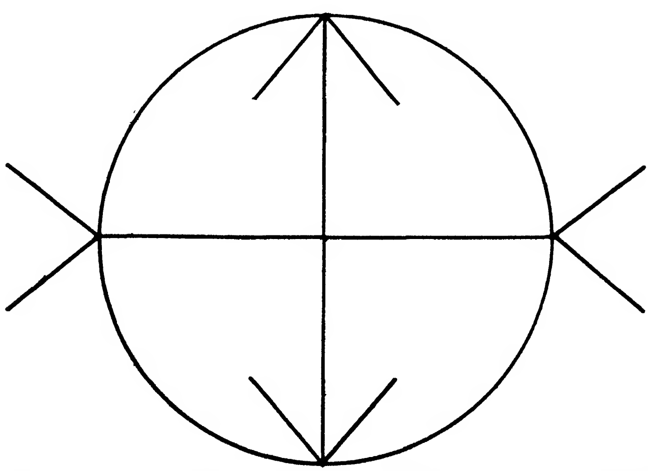

Fig. 30.—Dunlap's figure. Circle with apparently unequal diameters.

of the second position. No verifiable explanation for this alternation in reaction has been offered.

(e) *Illusions of area.* Contrast effects of area and linear extent are common. A given area appears larger when adjacent to a small area than when adjacent to a large one. A line, beside

a shorter one sometimes appears longer than it does when beside a longer line. In the Jastrow illusion (Fig. 28) two equal and exactly similar areas appear unequal because the adjacent lines of the two are unequal. In the Müller-Lyer illusion (Fig. 29), which is the converse of the Jastrow illusion, two equal lines appear of unequal length, because they are important diameters of unequal areas. In a third illusion (Fig. 30) (first described by the author), the effect of the unequal area on the equal lines carries over a third step, and makes a circle appear distorted.

CHAPTER XIV

THE THINKING PROCESS

§1. The thought reaction.

We know that there are two ways of being conscious of objects, which we distinguish as perceiving and thinking: or, abstractly, as perception and thought. The attempt to define these terms leads to mere circumlocutions, but the processes to which they refer can be pointed out in concrete experiences. I *perceive* the vase of roses now on the table before me, in full daylight. An hour from now, when I am in another room, I may *think* of them: in this particular case, I may *imagine* them. The different types of thought—imagination, memory, conception—have been discussed already in Chapter VIII.

For the detailed understanding of thought; for the analysis of the conditions under which it occurs, and the ascertaining of its laws, it is necessary to reduce it to a psychobiological basis, just as has been done for perception. The empirical similarities between thought and perception, and the dependence of the second upon the first, as already discussed, indicate that the basis of the two processes is essentially the same: that thought, like perception, is intrinsically a reaction. The principle of parsimony, moreover, would necessitate our considering this hypothesis, and determining how far it fits the known facts and promotes further investigation.

Reaction involves stimulation. Every reaction begins in the activity of receptors, which must be stimulated in some definite way. We must seek in the body therefore, for the neural mechanism capable of sustaining a thought reaction, and seek for the probable stimulus. At the outset, we must exclude the receptors of the so-called special senses: vision, audition, gustation, olfaction, and the dermal senses. In the first place, the functioning of these initiates perception: in the second place, thought, even thought of objects which appeal perceptually to these senses, may

proceed when the receptors are excluded from functioning: and, in the third place, none of the known methods of stimulating these receptors would account for the salient peculiarities of the thought reactions.

The outstanding characteristic of thought is that it may be brought about by, (1) perception, and (2) by preceding thought. Under the title of the *association of ideas,* this feature of thought was studied early in the history of psychology, and its laws formulated with considerable accuracy before any biological foundation was possible. Perceiving one thing makes us think of another thing: and thinking of one thing leads to—causes—the thinking of another. Thoughts frequently become "associated" or linked together in long "trains." In this respect, thought apparently differs sharply from perception, where each successive act needs a new stimulus. The difference is not really so great as it seems; nevertheless, it is important. Perceptions, other than those of the visceral and somatic senses, normally require stimuli from outside of the organism. Perceiving one thing *may* lead to the perception of another, provided the stimulus for the other is present. Thus, your hearing the door open may lead to, or may involve, the reaction of turning your head and eyes in such a direction that you see the person entering the room. But the perception or the thought of one thing leads to the thought of another even without the intervention of an outside stimulation.

The requirements for the organic mechanism of the thought reaction are therefore clear. The mechanism must be such that a perceptual reaction may cause, or initiate a thought reaction, and a thought reaction may initiate a second thought reaction. This means, still more specifically, that the end of the one reaction must be the beginning of the other.

Reactions end in two ways: in muscular activity, and in glandular activity. Glandular activity may lead to the stimulation of certain receptors eventually, but in general not immediately. The saliva secreted by the parotid and sublingual glands, for example, may flow into the mouth and stimulate touch receptors on the tongue surface. Glandular activities normally are rather gross affairs, the whole or a large part of a gland being affected in the same way. It is obvious

that the glandular activities cannot serve as the stimuli of thought reactions, since the thought reactions follow preceding reactions immediately, and are capable of finely graded variations.

Muscular activities, on the other hand, especially activities of the striped muscles, may affect receptors immediately, and are capable of indefinitely great complexities and variations. If we consider the different movements of which the arm, hand and fingers are capable; movements compounded from varying movement patterns of a relatively few muscles, we are impressed with the great range of such activities. If we consider the hundreds of thousands of definite and distinguishable "muscle patterns" of which the vocal muscles are capable in the enunciation of words, we are still more impressed. Since we know that all striped muscles contain multitudes of muscle spindles, in which receptors terminate, we know that each "muscle pattern" may give rise to a "stimulus pattern:" and that the distinguishability of these muscle patterns, so far as the individual himself is concerned, depends upon the possibility of different consequent reactions to the different stimulus patterns.

We have, therefore, in the striped muscles, exactly the mechanism which the known facts of thought process demand. The termination of a perceptual reaction can and does stimulate receptors which initiate a new reaction: and reactions which are both initiated and terminated by muscular activities may be linked or "associated" together almost endlessly. The conclusion that the muscle receptors are receptors for thought reactions is inescapable. Two objections to this view are rather obvious, but neither is fatal. First, it may be objected that the reaction initiated by muscle action should give perception of the muscle patterns. If, in the case of visual perception, the reaction gives perception of the object responsible for the stimulation, why should not the same result be found in kinesthetic reaction? Why should not the muscular activity which is, loosely speaking, the stimulation for the following reaction, be the content perceived by that reaction?

As a matter of fact, muscle reactions do, in many cases, give awareness of the action which initiates them. I may move my arm, or speak a word, and immediately "feel" the arm move-

ment, or the vocal movements. But in many cases, even in vision as we have seen earlier, the immediate content, or "sign," is not perceived, but its "meaning" is perceived. There is no essential difference between these cases and the thought reaction in which the "sign" is a muscle pattern, and is completely unperceived. In the case of the thought reaction, the "meaning" is called an "idea."

The second objection is that there are many cases of thinking in which no muscular activity is apparent. Granting that in most cases, activities of the vocal muscles, or, in the cases of children, activities of limb and trunk, as well as vocal muscles, may be detected by methods sufficiently refined, it may be claimed that in some adults, at some times, the most refined methods of measurement will show no muscular activities corresponding to the thoughts. This objection may be solid. We may even grant the possibility that in many cases where the muscular activity is observable (and these are the great majority of cases), the activities are reduced in energy to a point where they are not capable of initiating the next reaction. Such a condition, at least, is to be expected.

There may be, in other words, a short-circuiting mechanism,[109] which, when the reactions have become fixed, is interposed to obviate the necessity for the second reaction in an associated series having to wait for its initiation upon the completion of the first. This short-circuiting mechanism, if it exists, functions only for thoroughly learned sequences: not for reactions during the process of learning. It would function in precisely the same way for series of automatic reactions, such as those involved in plain knitting, when this has become practically automatic. In an early stage of the knitting process, the completion of one set of finger movements is the stimulus for the beginning of the next. But this process is somewhat slow, and may be speeded up by having a shorter efferent route (shorter than the route to the arm muscles),

[109]The known functions of the cerebellum point to it as the possible short-circuiting mechanism. But this is so far only conjectural. Any short circuiting mechanism must have a "point for point" correspondence with the muscular system, so that any muscular pattern can be reproduced in the short-circuiting mechanism. The cerebellum seems to have such a correspondence with the muscular system.

which leads to a switch-board from which the second reaction may be initiated before the first is completed. The muscular reaction still retains the possibility of checking, or modifying a wrong reaction.

It is not necessary to suppose that in general, particular muscular reactions are *necessarily* connected with particular "meaning" or thought-content. There is, at a given time, a definite muscular pattern which means a definite content, but the meaning and the muscle pattern have become connected through the ordinary processes of habit formation, and the connection is subject to further modifications. This is evident at once when we consider word reactions. "Oiseau," "bird" and "Vogel" may mean the same thing, although the reactions which produce these sounds are very different. And many other words have exactly the same meaning. The meaning of any one of these words, furthermore, is subject to variation, without losing its general application. "Apple" to the horticulturist, and "apple" to the child who has experienced only sweet, red apples, have different meanings. So, also, other muscle patterns such as movements of the fingers, may have various meanings built up by habit formation, as in the deaf-and-dumb sign language.

There are certain thought reactions which seem instinctive rather than habitual. The nodding of the head for assent, and the shaking for negation, are almost universal. Many "expressive" activities, like shrugging the shoulders and smiling, are not thought-reactions, but are emotional expressions which are thoroughly instinctive. It may be that all apparently instinctive thought-reactions are really developments of emotional expressions, as is probably the case in nodding and shaking the head. The question of "innate ideas" cannot, however, be settled out of hand.

The reaction for the thought of an object, and the perceptual reaction for the same object, are essentially the same, except for the initiations. For a certain individual, the perception of an apple involves the saying of the word apple, and the thought of an apple involves the saying of the same word. One reaction is initiated by visual, tactual, or olfactory stimuli: the other is initiated by muscular contractions of almost any pattern which

habit has linked up with the perception. The likeness of perception and thought is due to their essentially identical activity: the difference is in the exclusively muscular initiation of the second. The acquisition by a certain muscle pattern of the capacity to initiate a certain reaction which has developed as a perception is through the same sort of drainage which explains the development of the auditory-salivary reaction in Pavloff's dog.[110] If the muscular pattern is brought about in any way, at the time of a given perceptual reaction, the afferent current from the muscle pattern is drawn off into the established perceptual route, and the building of a habit of reaction is begun.

Verbal language, as the great medium of thought, becomes more and more important relatively as civilization and the age of the individual advance. Most educated adults think predominantly in vocal terms, and so the "language" of a people is the crystallized record of its thought processes. Most of us are, in fact, unable to think without actual formation of words, although normally we are not aware of the words, but are aware of the meanings. These words, in such cases, are not audible, or scarcely audible, since the vocal cords are not set in vibration: but aside from the breathing factors, the muscular patterns are quite faithfully reproduced. Often, persons thinking attentively, whisper the words so that others can hear them. This phenomenon lies at the basis of some cases of alleged thought-transference, and some of these cases are quite free from intentional fraud, since it is possible for one to catch the "idea" through auditory stimulation by a whispered word without being conscious of the word as an auditory object at all. This is but a particular case of being aware of meaning without sign.

In some cases, individuals reproduce, in thinking, not only the movements of the vocal organs proper, but also the breathing movements associated with them, and actually utter the words—"think aloud."

Among children, and perhaps among primitive peoples, verbal language does not predominate so strongly. Even among some civilized peoples, movements of the hands, shoulders, and trunk

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[110] See Chapter XI, p. 211.

muscles are employed in thinking, and of course in communicating thought. Non-verbal systems may easily be acquired by any one. Deaf and dumb persons, although they think in "words," use words made of finger and hand movements, and in many cases these movements may be observed when the individual is merely "thinking."

§2. The association of ideas.

"Association of ideas" is the term which has long been employed to denote the serial connection of thinking, and also the connection of thinking and perceiving which we have already described. "Association" is only a special case of habit formation, and occurs exactly as does the serial connection of reactions of any kind. The process can be illustrated most clearly from the learning of "nonsense syllables," a form of material much used in psychological laboratories for the investigation of association and memory.

Let us suppose that a reactor is required to "learn" a list of six nonsense-syllables: NOF, KEV, TOL, SEB, FUD, MIP. These syllables are presented to him, one at a time, visually (printed in clear type), for one second each: and he is required to "learn the series," that is, to associate them serially, so that he can recite the list, beginning with the first one, without error. The reaction for the first syllable, in short, must initiate the reaction for the second, the second for the third, and so on.

What happens is illustrated by the diagram of Fig. 31. As the reactor reads the syllables in succession, the reading of each becomes a definite reaction, which usually will be the pronunciation of the syllables. The arcs of the several reactions are represented in the figure by the lines NOF-N, KEV-K, TOL-T, and so on, representing arcs from the receptors at NOF, etc., through the central nervous system to the muscles, at N, etc., which participate in the reaction.

The reaction NOF-N, by its muscle pattern N, excites receptors, giving rise to the afferent current n-n′. But since the next stimulus word, KEV, is presented before this reaction effect has ceased, the afferent current n-n′ is "drained" or drawn off into the transit TOL-T, and so on.

If the presentation and reading of the stimulus syllable is repeated several times, the arcs n-k, k-t, t-s, s-f, and f-m become fixed, temporarily at least, and the series of actions N, K, T, S, F, and M may occur in the order determined by the habits formed, without the original stimuli. In other words, the reactor may "repeat the series from memory."

In order that the series of thought reactions may be brought about, after it has been "learned," it is necessary to set going the first reaction of the series. This might be done by presenting the

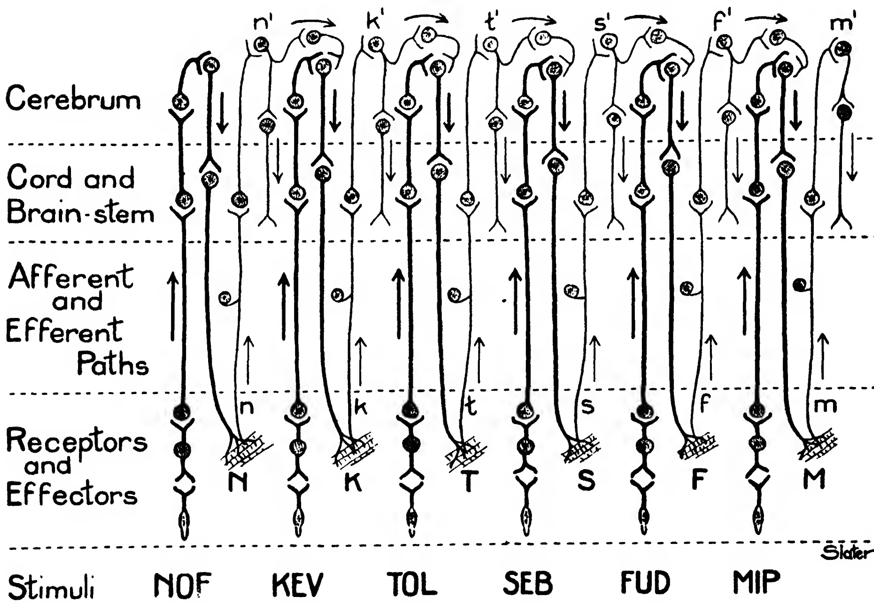

Fig. 31.—Scheme of the pathways involved in the learning of a series of nonsense syllables. Assuming the previous development of the reactions perceptual NOF-N, KEV-K, TOL-T, SEB-S, FUD-F, and MIP-M, represented by the heavy lines, the lighter lines indicate the pathways formed from action to action, which eventually enable the successive actions to occur without the primary stimuli.

first stimulus word again: but ordinarily, after the reactor has "learned" the series, he demonstrates the fact by reciting it without even this aid. What, then, produces the first reaction in the series? Or, in terminology of less definite conceptions which merely ascribes the successive recalls to association between terms, what association recalls the first term of the series? The explanation of the first syllable recall, although not simple, is in the same principle which gives the recall of the successive terms.

In repeating the series, in learning, the last syllable becomes "associated" with the first, so that the completion of the series as presentation tends to bring about next the reaction of the first syllable. Other stimuli, such as the experimenter's request to repeat the series: the appearance of the apparatus, at the conclusion of a series, may also be associated with the first word. The actually important factors vary with the particular conditions of the experiment. In short series, however, there is a persistence of the first word: a preservation of the first reaction; which it is at present impossible to explain. After reading a short series of words over but once, one can immediately repeat the first word, although no associations directly from the last word to the first have been formed. We might suppose that the recall is backwards through other associations just formed in a forward direction: but this would not explain why the first term is recalled before the second and third, and sometimes why the second, third, or other intervening terms cannot be recalled at all.

The first reaction in such a series has especial importance, because of the need for recalling it. The other terms may be recalled through the linkage of reactions, provided the first can be recalled. Hence the reactor in some way puts especial emphasis upon the first reaction, and it leaves its arc for some minutes ready to resume activity again when conflicting arcs are out of the way. The preservation of activity of elements or groups of elements in the nervous system must be assumed, whatever further hypothesis is held, in order to account for these phenomena, and it is not peculiar to the reaction hypothesis of thought which is here upheld.

§3. Mediate associations.

It is possible that the diagram of Figure 31 should be modified by additional lines, showing integration of each muscle-to-muscle transit, with not merely the next perceptual arc, but also with two or more of the following arcs. That n-n′, for example, should be shown as discharging not only into KEV-K, but also at TOL-T and SIB-S. Certain experimental results, to be described later, suggest this scheme, although it is not at present positively indicated. In repeating a series almost completely

learned, it frequently happens that a term, for example, the fifth syllable in a list of ten, is skipped or omitted, the fourth term bringing up the sixth immediately; that is, the fourth reaction bringing about the sixth. There are many other cases, in which a middle term, previously associated with a preceding and with a following term, drops out, and the first and third terms appear directly associated. What actually happens in such transformation is not known, and remains to be discovered by experimental work.

§4. Formation of automatisms.

The process in the association of ideas is precisely that in the habitual enchainment of actions of all kinds, whether the actions are ultimately conscious or unconscious. The formation of the habit of waltzing, *i. e.,* learning to waltz, may be illustrated by a diagram similar to that of Figure 16. The perceptual arcs, in this case, will be the response to the verbal commands, and pressure signals of the teacher, and the ultimate result is the formation of a chain of reactions of the leg and trunk muscles, so that the movement pattern in taking the second position of the feet is the stimulus for the reaction of taking the third position, and so on: the sixth reaction being connected with the first again, so that the series of movements formed is cyclically connected, and will continue, after being well learned, with a minimum of perceptual control. The music, the stimulation from one's partner, and from other dancers on the floor, continues, however, as a source of perceptual control, the dancing never being permitted to become a purely automatic process.

§5. Reasoning.

All thinking consists of reactions which may be divided into two classes: reactions involving neural transits already established by association; and reactions in which new associative connections are established. Sequences of such reactions occur under widely varying conditions, and the forms of thought are hence diverse. In an elementary treatise, it is not desirable to trace all possible forms, neither would it be possible at present to trace them, for psychology has only recently begun the scientific study of thought processes, and has, as yet, but sketched the outline of

this study. There is, however, one form of thought into which it is both possible and necessary to go in some detail: this is the form commonly called reasoning, or inferential thinking.

Logic deals with reasoning as an art, whereas psychology must deal with it from the point of view of scientific analysis. Logic assumes reasoning as a fact, without attempting to account for it, and examines the rules by which we are enabled to judge whether reasoning is true (or useful) or false (or disadvantageous). Psychology is concerned primarily with the explanation of the reaction processes which actually constitute reasoning, whether true or false from the logical point of view. In the study of reasoning, therefore, each science has its separate work, and neither can take the place of the other.

The characteristic feature of reasoning is the formation of a judgment. A judgment, in formal logic, is expressed as a proposition, consisting of subject and predicate, or of subject, predicate and copula. "Gold is heavy," for example, is a proposition in which "Gold" is the subject, "heavy" the predicate, and "is" the copula. "Gold melts at the temperature of 1967° F.," is a proposition in which the predicate is "melts at the temperature of 1967°," and the copula is implicit. Formal logic transforms this proposition into the form, "Gold is (a metal, or stuff) which melts at a temperature of 1967°," in order to make the copula explicit, because formal logic deals only with the relation of existence, which is expressed by the copula (some form of the verb "to be") and does not deal with other relations and with actions. Psychology, however, deals with all relations, and with actions, and hence does not transform its judgments into the copulative logical form, although it must, of course, express them as propositions when it discusses them. A certain judgment in regard to a dog, for example, actually occurs in a form which is directly expressed in the proposition "the dog barks." Psychology examines the judgment in this form, and not in the artificial form "the dog is an animal which barks," which logic requires. Of course, the judgment may actually occur in the latter form in a certain case—and then psychology must examine it in that form; but in either case,

the judgment must be examined in the form in which it actually occurs in thinking.

A proposition always expresses a relation between a subject and a predicate, or between a subject and objects not specified, as in the instances given. For an act ascribed to a subject always involves relations between the subject and other objects. From the nature of the proposition we may arrive at the nature of the judgment, since it should make no essential difference whether the judgment occurs as a reaction or reactions involving the vocal muscles, or some other muscles. In any case, the judgment is a succession of two thought reactions: and the content of at least one of these is a concept, involving a relation or relation-complex to the content of the other, or else involving the other with a relation or relation-complex added. In thinking "the dog barks," in any way, there is a reaction involving awareness of "dog," and a second reaction, which may be a particular idea, involving the same "dog" with the added relational system of "barking activity." In the judgment "Gold is heavy," the first idea may be a concept including the relation (to the earth and other objects) "heavy," and the second may then single out for its content the relation "heavy" already included in the first content. This judgment is commonly called analytic, and the first one is called synthetic. In the synthetic judgment, the second idea is richer in content, in some respect, than is the first: in the analytic judgment, the second idea has for its content a limited part of the content of the first, or at least a limited part of the content is more vividly attended to than in the first. Judgments must, in general, fall under one or the other of these classes, unless the second idea is merely the repetition of the first, in which case we do not speak of the sequence as a judgment, but call it the repetition of an idea.

The succession of thought reactions in a judgment may be merely one which has become habitual. In that case, the series follows the general law of habit, and requires no special consideration in this place. The important matter is the formation of a new judgment, that is, the formation of a new sequence of thought reactions of the sort we have been describing.

The formation of an analytic judgment depends upon condi-

tions which are usually very complex, involving the residual effects of many preceding stimulations and reactions. There is no simple and general set of conditions which can be described as accounting for the process. The difficulties in respect to an analytic judgment are precisely similar to those in respect to analytic perceptions. Often, the perception of an object as a whole is followed by the perception of a limited part of the same object, as in the case where you perceive some one's face as "odd looking," and then perceive one eye as having a cast in it. Such instances of analysis are so common that we may never reflect on the difficulty of explaining them. The analytic judgment is of precisely the same type, and together with the analytic perception constitute an important problem for psychological study, a problem which so far has not been attacked seriously, and concerning which it is of little use to theorize.

The conditions determining the synthetic judgment are simpler, involving the established principles of habit formation in an intelligible way, although the process is modified and directed by the same complex effects of preceding reactions which determine the formation of the analytic judgment. Here, also, the conditions are closely paralleled by those determining a certain form of perceptual development, and we may usefully consider the perceptual and the ideational processes together.

Suppose that in a salesroom you are examining an electric toaster placed before you by the salesman. You perceive it first as "electric toaster," the reaction involving that perception having been built up by a succession of preceding reactions. But you do not perceive it as "good toaster." Next, you perceive the label "Genax Electrical Company," whereupon the toaster is perceived as "made by Genax," and immediately thereafter the toaster is perceived as "good toaster" (toaster it is safe to buy). This process, as described occurs if you have previously formed the concept of "Genax products" ("manufactured by Genax"), as "good" products, so that the action-pattern "Genax product" initiates at once the reaction terminating in the action-pattern "good," or "good Genax product" (synthetic form). If this conceptual and judgmental tendency has been established, the constant drainage tendency of the central neurons establishes the

connection between the stimulus pattern of the particular toaster and the action pattern of "good," and the toaster is perceived as good.

A closely similar process occurs where the object (corresponding to the toaster) is not perceived, but thought-of, and the modification of the original reaction, involving an addition to or modification of the original content, is brought about in any way whatsoever. Assume that the transaction is not completed in the salesroom, because the completion of the synthetic judgment is inhibited by failure to notice the label, or by the absence of the judgment "Genax products are good." Later, perhaps by telephone, the information as to the label is received; or the judgment characterizing this firm's products is formed through consultation of some one whose judgments on such points you adopt; and the synthetic judgment may be completed.

The foregoing brief sketch of certain features of reasoning is useful merely as an indication that it is possible to work out the psychological details of complicated thought processes in a scientific way, and that the work still remains to be done. Although logic has treated reasoning from its point of view in a comprehensive way, psychology has so far done very little in this part of its field. Psychologists have, in the main, pursued two policies here: either they have left reasoning processes out of consideration, or they have treated them purely from the logical point of view, the paragraphs on this topic in many text books being but paraphrases of the logician's treatment. This has not been for want of interest or want of appreciation of the importance of the topic, but from the lack hitherto of a scientific basis from which psychological development is possible. We may confidently expect that there will be, in the immediate future, experimental work in this field, and the reproach that experimental psychology concerns itself almost exclusively with sense perception will be removed.

CHAPTER XV

AFFECTIVE EXPERIENCE

§1. Feeling and emotion.

In the preceding chapters, we have apparently neglected a large and important class of content, and the reaction processes through which it is perceived. *Sentienda* and *relations* make up the outer world: but there is an inner world of *feeling* which is just as real as the outer world, and in some respects more important. What is this inner world, and how do we experience it? The answering of this question can be delayed no longer.

Under the general names of "feelings and emotions" we customarily include such things as joy, rage, melancholy, pain, hunger, fatigue, thirst, amourousness, irritation, pleasure, desire, and sometimes even such obviously sensory contents as tickle, warmth and touch. The apparent nondescriptness of this group of things has led to a distinction being raised between the obvious sentienda included in the group, and those things which are less obviously sentienda, and the application of the terms *affections, affects* or *affective contents* to the latter. Whether this distinction is useful or harmful will be considered later.

Among the affective contents, it has been the custom of psychologists to distinguish the simpler affects from the more complex, and to apply the term *feelings* to the former, and the term *emotions* to the latter. In popular usage, however, although the term "emotion" has been restricted as among psychologists, the term "feeling" has been applied to the whole group. There seems to be no use in attempting to oppose popular usage on this point, and we shall therefore follow it.

§2. The nature of feeling.

Feelings are actual data in experience. They are facts, not inferences; and they are content of which we are aware. They are comparable to sentienda, in that they have intensity, duration, and sometimes even extensity, and are spatial to the extent of

being located within the body. Not only the feelings which are classed as sentienda, such as pain and fatigue: but also the unquestionably affective contents such as joy, amorousness, and rage, are distinctly within the confines of my body; not in the outer world, and not, like awareness, exempt from space limitations.

Feelings, then, must be something experienced through reactions which are initiated by the stimulation of receptors just as sentienda are experienced. We might say that feelings are perceived, but it is better to retain the term perception to apply to external perception only, and apply the more general term *intuition* to internal experiencing.

The existence of a class of sentienda (pain, warmth, fatigue) which are persistently classed with feelings, and the existence of a second class of content, (hunger, thirst, fullness, etc.) which are sometimes classed as sentienda and sometimes as affects, gives the clue to the real nature of feelings. They are *organic,* or *bodily sentienda*: details of the soma and viscera, and of changes in soma and viscera, as those details and changes are intuited or experienced. The classification of warmth, cold, pain and pressure as feelings is quite intelligible. In so far as warmth and cold are properties of the body, they may truly be feelings. In so far as they are properties of external objects, they cannot be feelings.

But even those contents which are always properties of the body may at times not be feelings. Pain, always in the body, may be a feeling, or it may be a sentiendum of the organic sense. Hunger and thirst are not classed merely inconsistently now as feelings, now as sense data. Actually, these data may be feelings at one time, and not at others.

The essential characteristic of a feeling is its vagueness and lack of definitely perceived pattern. It is not even definitely localized; in its most truly characteristic condition, it is just "inside." However complex it may really be, its complexities are not perceived. In so far as the feeling is analyzed and localized, it ceases to be a feeling and becomes organic sense-data. The emotion as intuited may be compared to the sound of an orchestra to a man who has previously heard no musical instruments, but whose auditory mechanism is perfect. The sound is to him a vast,

insistent, *general* noise, however rich and impressive it may be. The shrilling of the chorus of strings in one passage, and the blaring of the brasses in another may be markedly different to him; but he discriminates no details in either. The sound to him is actually a *feeling*,[111] added to his complement of bodily feelings. Even to the partially sophisticated listener, and to the trained listener, in his unanalytical moments, the orchestral synthesis has a feeling characteristic, which is lost when the pattern is analyzed.

The bodily sentienda are preeminently fitted to merge as feelings, because of the great difficulty in analyzing and localizing them. The auditory, dermal and visual data are analyzable because they are readily variable. By controlling the stimulus, and by motor adjustments, fine variations are produced in the stimulation, and the data are thereby analyzed. But in the case of the viscera, and to a large extent, in the case of the soma, gross variation in stimulation, and that not readily controllable, is the most that is possible.

The organic sense data, therefore, remain largely feelings; the rich and general background of experience against which external objects are perceived, and are analytically reduced to mere sense data only by great labor, and even then only in small part. For this reason it is inadvisable to speak of "perceiving" the emotion or feeling, but rather to speak of *apprehending* or "intuiting" it, since "perception" usually connotes an analytical awareness in which details of the content are to some extent distinguished.

§3. Feeling and reaction.

The possibility of experiencing feelings depends primarily upon the receptors which have their distal terminations distributed through the soma and viscera. These receptors have their cell bodies either in spinal ganglia, or in cranial ganglia, and send their dendrites to the viscera through the autonomic division of the nervous system: and to the striped muscles, tendons, fascia, and skin, through the spinal and cranial nerves.

The visceral organs are the most important source of feeling,

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[111] This is, of course, over and above the bodily feelings aroused by the music, although the latter are directly affected by the former.

and hence the afferent autonomic system is the most important "sensory" system for feeling: but we must not forget that muscular and even dermal components enter into many emotions. The muscular system plays a complicated rôle in mental life.

If we consider in detail the various tissues and organs of the body in which receptors terminate, we obtain some conception of the possible range of bodily qualities. The skin and mucous membrane we have considered already. There are sensory endings in the superficial fascia which lie between the skin and the striped muscles, and in the deep or inverting fascia, which lie between the muscular layers in certain parts of the body. The omenta and mesenteries which suspend and bind the stomach and intestines; the peritoneum and pleuræ, which line the abdominal, sacral and thoracic cavities, and in part cover the viscera externally; the periosteum, which covers the bones; and the perimysium, which envelopes and penetrates striped muscles, are also connective tissue structures which are supplied with sensory neurons.

The heart, and the bloodvessels throughout the soma and viscera, have sensory endings either in their connective tissues, or in their muscles. The various parts of the alimentary canal—gullet, stomach, small and large intestines—contain receptorial terminations, at least in their connective tissue coats and epithelial linings. The urinary system of kidneys, bladder and ducts, and also the liver, pancreas and the other glands, are all supplied with afferent fibers. The generative organs, not merely the ex-
these receptorial systems may be points of origin of reactions, and
internal organs of both, have a rich afferent supply. And all of these receptorial systems may be points of origin of reactions, and hence of affective experience. It is worth while even to inquire whether there may not be receptors in the nerve tissue itself, since the feeling of interest seems to be an actual state of the nervous system, and not of any of the non-neural tissues. How many diverse feelings can arise in each of these tissues and organs, and to what extent the same feeling may arise in different structures, remains yet to be discovered.

§4. The simple feelings.

There are a number of feelings which appear to be simple, and which may be considered as at least *relatively* simple: (1) sus-

pense, (2) disagreeableness, (3) pleasantness, (4) excitement, (5) fatigue, (6) strain, (7) relaxation, (8) depression, (9) thirst, (10) fullness (of alimentary canal and bladder), (11) emptiness, (12) malaise, (13) nausea, (14) dizziness, (15) exhilaration, (16) interest, (17) a localized sex-feeling, (18) suffocation, (19) relief, (20) satisfaction, (21) revulsion, (22) tender feeling, (23) anticipation, (24) choking, (25) retrospection, (26) desire, and, of course, pressure, pain, warmth and cold. Undoubtedly there is an enormous number of other feelings which are as nearly simple as these, but which have not as yet been analyzed out of the complexes in which they occur.

A number of the feelings listed above are, perhaps, not simple, but complexes of simple feelings, and may eventually be analyzed into their elements. They function, however, as rather constant radicals, if they are not actually simple. Some of them may seem to be types including a number of qualitatively different feelings, rather than single feelings.

There is a recognized difference, for example, between fullness of the stomach of the small intestines, of the colon, of the rectum and of the bladder. There may seem to be different sorts of excitement and relief, irritation and satisfaction. But it is quite probable that the differences are not in the feelings named, but in attendant feelings of other sorts, which uniformly accompany these feelings. The attendant feelings in some cases of fullness seem to be peculiar to the organs in which the fullness arises; but in other cases, they probably arise from different organs or tissues, or from definite processes therein.

The great mass of feelings such as hunger, pleasure, joy, sorrow, fear and the whole list of emotions, seem to be complexes of the feelings named above, together with feelings as yet unnamed, and the great variation in these emotions and other complex feelings undoubtedly depends upon the variation in the elements or radicals present. These variations are so great that there is no possibility of a sharply defined classification of the emotions. Consider, for example, the closely related and relatively simple emotions of approval, disapproval and pathos. Approval includes satisfaction (apparently an alimentary feeling localized

in the gullet and stomach) with some pleasantness, a slight element of relaxation, and several feelings not yet analyzed. Disapproval includes revulsion (also an alimentary feeling) as its most prominent element, together with disagreeableness, some strain, and other feelings. Pathos is not a combination of approval and disapproval, but combines the satisfaction and revulsion, which are the most characteristic components of these two, with an element of excitement, and varying other components from approval and disapproval. Sometimes there is strain, sometimes relaxation: sometimes pleasantness, sometimes unpleasantness.

Certain of the feelings are characteristically arranged in opposing pairs. Strain and relaxation, pleasantness and unpleasantness, satisfaction and revulsion, fatigue and exhilaration, fullness and emptiness, malaise and relief, are such pairs. This antagonistic relation suggests the dependence of the pair on the same organ or tissue, under opposed conditions. Strain and relaxation are probably muscular. Emptiness and fullness are of course derived from opposing conditions of the bladder and alimentary canal. Satisfaction and revulsion may be associated with the peristaltic and antiperistaltic movements of the gullet and stomach. This does not mean that both members of a pair may not actually be present in a single affective content, since one part of an organ or system of tissues may exhibit one action or condition, while another part exhibits the reverse. Pleasantness and unpleasantness, however, seem to be conditions or processes in some organ or system which cannot work partially, but goes as a whole. The most plausible processes as a basis for these feelings have been claimed to be the tumescence and detumescence of the erectile parts of the generative organs, but this assumption is merely tentative, and hardly yet sufficiently indicated as a working hypothesis. We should remember, however, that these processes are demonstrable in the very young baby, in whom they have not as yet become a true sex function, and that their feeling significance is unquestionably much wider than the sexual or reproductive emotions.

§5. Emotions, moods and sentiments.

An emotion is a process which has a definite course of rise, duration and subsidence, and is usually dependent upon (really caused by) an external stimulus pattern. In the case of anger, for example, a stimulus pattern which may consist of a blow, word or visual details, causes a reaction which terminates in profound visceral disturbances, together with somatic changes. The reaction involves the perception of the affront, or threat; and its organic termination pattern (involving activities of smooth and striped muscle, glandular activities and probably other chemical changes) really *is* the emotion of anger. This action pattern is also a stimulus pattern, since it stimulates receptors terminating in the visceral and somatic tissues, and thus initiates a new reaction, in which the emotion is experienced. If the afferent fibers from the soma and viscera were blocked, but the efferent fibers to these tissues not interfered with, the emotion would occur, but it would not be experienced. The animal would exhibit all the expressions of anger but would not experience it.

In such emotions, two groups of component content may be distinguished. (1) A quick component, due to the activity of the muscular systems, both the striped and the smooth. Tension of muscles of the back and limbs; violent contraction of certain muscle groups, as in "starting," alteration of the breathing process and heart beat, alteration in arterial tension, evidenced externally by flushing and paling, contraction and relaxation of the urinary and anal sphincters; and important changes in peristaltic and other activities of the alimentary canal; are familiar facts in emotion, and these occur as the immediate termini of the perceptual reaction and as the immediate initiation of new reactions. (2) The glandular effects, however, do not affect receptors so quickly. Increased and decreased secretion of the adrenal, thyroid and other glands require some seconds to affect the visceral and somatic stimulus pattern, since the secretions (hormones) of the ductless glands must be carried in the blood stream to other parts of the organism. These gland products are effective by changing the activity of muscle, and probably also as direct chemical excitants of receptors terminating in various connective tissues.

The quick and slow components may be recognized readily in

such an emotion as fear, due to a sudden stimulus. In some cases, the quick component occurs, with the slow component so minimal that we call the complex not fear, but "being startled." The comparison of these two emotions gives some notion of the importance of the visceral activities, as compared with the somatic, and also of the difficulty in estimating the nature of an emotion by its externally perceptible factors. An emotion of fear in which the activity of the striped muscles is very small may be extremely intense because of powerful visceral reactions, and an emotion in which there is a strong external factor of the sort commonly present in fear may have little of the fear characteristics because of the mildness of the visceral factors. The comparison of the emotions of children with those of adults is especially difficult on this account. We are unable at present to determine whether children under two years of age really experience any emotion such as adults call "fear."

In addition to definite emotions, there are organic conditions of relatively prolonged duration, which are conventionally called *moods*. A mood may be described as being in part a tendency to be thrown easily into an emotion, or simpler feeling, of a definite type. A reactor in an angry mood is easily roused to anger by external stimulus patterns which, in other moods, would not anger him. In a depressed mood, occurrences which would ordinarily be innocuous, bring on a strong feeling of depression. In an elated mood, trivial situations call forth joy or other elated emotions. These moods are familiar facts in the lower animals as well as in men, and may be due to maladjustments or perfections of functioning of the organism, quite aside from specific external stimuli, or they may be due largely to the effects of environmental factors on the organism. Nervous disease, glandular disease, febrile conditions, digestive disorders, drugs such as alcohol and hashish, loss of sleep, variation in sexual function (such as the menstrual cycle in the female), over-work, general well-being, worries, failures in important projects, success and flattery, overstimulation of visual and auditory functions, and a host of other external and internal conditions, have their well marked concomitant moods. The "lioness robbed of her whelps," and the "strong man rejoicing to run a race" are classic illustrations of moodi-

ness. For the unusual affective response of our friends we daily seek explanations in conjectured occurrences or ailments which could be responsible for the moods they display.

Moods are in most cases more than mere "tendencies" which might be ascribed to the nervous system alone. Some trace, often a considerable one, of the feeling or feeling complex persists as a continuous content during the time the mood lasts. In an irritable mood, the irritated feeling may be continuous, rising to intense pitches when certain stimuli operate, and sinking to a lower level during the interval between such stimuli. The angry mood is more than a succession of fits of anger, with the "tendency" bridging the gaps: It involves in many cases a persistence of the angry feeling, even when there is no anger at or over specific stimulus-patterns. Depressed and elated moods especially, showing a continuous depressed or elated feeling, are not dependent upon any specific external occurrence. These persistent feelings are especially marked in the insane and neurotic, in many of whom no combination of external impressions can inhibit the depression or elation, even temporarily, while the mood lasts.

In this continuousness is the chief distinction between a mood and an emotion. The emotion, aroused by a specific stimulus-pattern, is integrated consciously with the object or event concomitant with that pattern. The emotion is experienced as a background for, or adjunct to, the object or event perceived, the perception of which is the real cause of the anger. When a man steps into the seat I have vacated for a moment, my anger is *at* his act. That is: I experience the anger and his act as a single pattern. And in such a case, the emotion subsides with the subsidence of the perception or thought which aroused it. I do not carry the emotion over to other objects and other events, which would not in themselves arouse it.[112]

The characteristic of the mood is that it attaches to, and is experienced with, a wide range of objects and events which stimulate the reactor while the mood persists. If I am really in an angry mood, I not only am intensely angry at the act of the man

[112]It is true, however, that a strong emotion may leave a transitory mood of the same kind behind it. Often, however, it has the reverse effect, and leaves the reactor less susceptible to stimuli which normally arouse that emotion.

who usurps the seat: I am angry with the innocent passenger who is thrown against me by a lurch in the car; I am angry with the conductor who seems to be slow in giving me my change; I am angry at the newspaper which refuses to fold conveniently for my reading; and at a long list of petty circumstances which are effective really because the anger is there, ready to be attached to any object, and to rise in intensity in the process of integration.

In contrast with these tendencies to specific emotional reactions without much distinction of stimuli, there are tendencies to systems of specific emotional reactions, each under specific environmental conditions, but dependent upon definite functional conditions of the organism, which are of great importance. These systematic tendencies are called *sentiments.*

Patriotism and parental love are conspicuous examples of sentiments. The parent who loves the child is in such an organic condition that he experiences tender emotions when he caresses, or even when he contemplates the child, in the absence of conflicting stimulations. If the child is injured, he experiences grief; when he perceives or thinks about the child's condition as such. When he is aware of the act of some one which injures or threatens the child, anger arises. When the child shows desirable traits, pride enters. If the child is vicious, chagrin or shame occurs. And so on, through practically the whole range of emotions and simpler feelings. No one of these emotions, nor the whole gamut taken together, constitute parental love: parental love is the tendency, resident in the organism, and organized by the circumstances which have made the man a parent, to experience these emotions in a definite and predictable way, as results of specific environmental patterns into which the child enters.

§6. The driving force of feelings.

While considering the feelings as products, we must not ignore their functions as causes. The effects of feelings in the reactions which follow them are profound, and the method of production of these effects is made clear by the analysis which scientific psychology makes of the feelings themselves. A feeling is always a real organic process or condition, and is a stimulus pattern

which is the beginning of a reaction pattern. The feelings are powerful stimuli, and the effect of the reactions they initiate are among the most important determining influences in our total reaction system; not more important than the hereditary constitution of the reactive machinery, but important as the chief means through which both hereditary tendencies and the modifying effects of the environment operate.

The afferent current derived from feelings must release efferent current which must go somewhere, to some muscles and glands, and must produce important effects. If the succeeding perceptual and thought reactions draw off this efferent current into their proper channels, the results of these reactions may be usefully intensified and extended. In this case the emotions are said to be "under control." The emotional discharge, however, may seriously interfere with the normal efferent discharge pattern of the perceptual and ideational reactions, either making these latter ill adapted for the proper adjustment to environment, or even blocking the normal efferent pathways completely by drawing off the discharge into new wholly emotional responses. In such cases the emotions are said to be "uncontrolled." To say that control of emotions is the most important thing in life is trite, but the saying can hardly be overemphasized.

It has long been surmised that feeling is the most important controlling factor in the learning process, and its function here has been questioned only because of a confused view of psychology in which the feelings were considered as a sort of "purely mental" content, quite remote from the world of muscles, glands and actions, and therefore having no means of influencing that world. Of course, feelings are as "mental" as any object or content can be: but they are also real, effective factors in the body, as "common sense" has long supposed, and as scientific psychology explains them to be.

The confused view which psychology formerly had regarding the feeling is partly responsible for our lack of detailed information concerning the practical working of feelings in connection with perceptual and thought reactions. The extreme difficulty in experimental work on feelings is the other cause of our ignorance. The study of feeling is one of the most important tasks of experi-

mental psychology in the future, and there is no ground for doubt that the study will advance satisfactorily. Too much effort has been put in the past into the so-called "introspective method" in studying feeling, and the substitution of the experimental method will unquestionably make future efforts more profitable.

Certain practical points in regard to feeling and the learning process are fairly well established. Pleasant emotions, if of moderate intensity, are favorable to the fixation of habits, and unpleasant emotions inhibit the fixation. Both, therefore, may contribute to the learning process. Reward and punishment as aids to learning are both practically and experimentally approved. Strong emotion of any kind is apt to be detrimental: the general consideration of the connection of feelings with reactions would lead us to expect this Interest in the stimulus pattern is profoundly effective in all kinds of learning, and desire of the finished result is also of great importance. With regard to other details, we have nearly all to learn.

§7. Desire or conation.

Desires are feelings of especial importance, apparently vital in their bearing on life. Without desire the complex animal would probably not adjust himself to the environment, and would shortly die as a result of mal-adjustment.

It might be supposed that there is only one sort of desire, and that the difference between the various "desires" is a difference solely in the perceptual or thought content to which the desire attaches. While it is true that in many cases the desires are differentiated solely by their objects, it seems probable to the author that there are several fundamentally different desires and that these desires are resident in specific parts of the organism. It is not to be assumed at present that these desires are literally simple. They may be complexes; but if so, they are of a relatively constant sort, (quasi-elements or radicals) the constituent elements in any one sort of desire being united in a rather invariable way, and functioning as a group or radical. If that be true, it may also be true that in all desires there is one common element. Nevertheless, the several sorts of desire would still be differentiated by their characteristic non-common element.

The list of desires which is proposed as fundamental is as follows:

1. Desire of aliment (food and drink).
2. Desire of excretion (to be rid of disturbing things).
3. Desire of rest.
4. Desire of activity.
5. Desire of shelter (protection from disagreeable factors in the environment).
6. Desire of conformity (doing as others do, or as a leader does).
7. Desire of preeminence (leadership).
8. Desire of progeny (parental desire).
9. Desire of sex gratification (amatory desire).

These desires are designated by their most common objects, but this is merely a matter of description; ultimately we must identify them in some more direct way.[113] All of these may attach to objects of certain other types, and by such attachments, and combination of attachments, all the specific desires arise. Some of these primitive desires can perhaps attach to the objects to which the other desires also attach; but this is not possible throughout, and such attachment is perhaps rather exceptional than typical. Amatory desire and parental desire, for example, when attached to the same person, form a distinctly pathological combination,[114]

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[113]We might speculatively assign the desires to the various parts of the body as follows:

1 & 2. Alimentary canal and urinary system: associated with hunger, thirst, fullness, emptiness, etc.

3 & 4. Striped muscles: strain, relaxation, fatigue, etc.

5. Skin, mucous membrane and connective tissue: feeling of cold, warmth, pressure, pain, etc.

6 & 7. Circulatory and respiratory systems.

8 & 9. Sexual organs.

Such assignment is, however, to be regarded as merely illustrative of the definiteness of organic connection which is to be sought; not as prophetic of the results of final analysis. There is some reason to believe that activity of skeletal muscle is important in *all* desire.

[114]Such a combination exists in certain cases in which a father has an amatory desire toward his own daughter, or a mother toward her son. Also in cases in which a wife "babies" her husband, or a husband assumes a parental attitude toward his wife.

and when these two desires are normally combined, in the same total content, their objects are discriminably different.

Desires have both positive and negative aspects, in this respect suggesting the paired feelings. In place of desire of an object, there may be *aversion,* or *repugnance* to it. While it is possible that aversion for given objects may ultimately be accounted for as a combination of desires inhibiting the otherwise possible desire for that object, such explanation does not at present seem possible, and we must consider aversion along with desires. We shall speak principally of the desires in the following pages, but must be understood always to be including the contrary conations. Since there is no accepted verb corresponding to *aversion,* we shall use the term *repugnance,* with the verb *repugn,* whenever we speak directly of these negative desires.

The practical importance of the desires is beyond question. Mere fatigue, for example, is not sufficient to impel the animal to take sufficient rest. Any one who has had the care of children knows that this is true. The sight of a child fighting against fatigue and the sleep tendency, and refusing to go to bed is familiar. And the tendency of children to go on with exhausting play in spite of extreme fatigue is also well known. The exciting stimulations in such cases do not inhibit the fatigue, but do inhibit the desire to rest. Even in the case of adults, the exigences of economic effort, and stimulation of complicated social life frequently lead to man's denying himself needed rest. Neither does the buffeting of the weather, or any other action of the environment, always suffice to draw an animal to shelter, or to ward off the injurious influences. For purposes of illustration, we may point to the cases in which the human animals expose themselves to inclement weather in response to the dictates of fashion, or sit in the cold rain to watch a football game. Hunger, or sex desire, or fear, may inhibit the shelter desire in the lower animals, and cause them to expose themselves to conditions from which the shelter desire normally protects them. Even bears, in-

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The passion for pet dogs displayed by some women is of a doubly perverted type: being not only the transference to a lower animal of emotional intent which should be expended upon human objects, but also the combination of the parental and amatory tendencies upon the same object.

sufficiently provided with fat against the hibernating period, have been known to break its customary inhibitions.

In the case of activity, full capacity and full need may be present in an indolent person, without the effective desire. In the lower animals, natural selection perhaps eliminates the indolent; but in modern civilization, the indolent man, unfortunately, is often nourished and allowed to propagate his kind. The desire of activity produces its most striking manifestation, quite apart from the impelling force of food, progenic and amatory desire, in the play activities of the young. In play of both man and beast, even the desires of conformity and preeminence are frequently absent, although these easily and characteristically enter into the play activities of groups, both human and infra-human.

Where parental desire is absent, amatory desire produces activities of a type which are decidedly lower than those in which the two sex desires combine. Such activities are lower in evaluation both from the point of view of general and of social psychology, and are powerful illustrations of the importance of desires. Parental desire without amatory, on the other hand, also occurs and likewise produces disastrous results. Marriage in which there is no amorous attraction between husband and wife, although relatively infrequent, is unfortunate, even for the purpose of satisfying the parental desire, and no child should be subjected to the influence of a home so constituted.

In their relation to the reactivities of the organism, desires follow the general laws of integration and habit formation to the full. Desires may be attached to new objects, and detached from primary objects, by the operation of drainage and repetition in the usual way. Objects which are associated with desired objects come to be desired, and objects associated with repugned objects come to be repugned. In this connecting or associating process there is, however, a distinct selective tendency: those objects (or events) which are causes of desired (or repugned) objects come to be desired (or repugned), but those objects which are *effects* of desired (or repugned) objects do not so uniformly come to be desired (or repugned). Desire "spreads" generally in the line of ascending causation: less generally in the line of descending causation. This point is of great importance, not only for

the understanding of the process of substitution of desires, but also for the understanding of the role that desire plays in the general learning process.

Desire ceases with the attainment of the object. In more scientific terms: desire attaches to (is integrated with) an anticipated thought object; never with a presently perceived object, or a retrospective thought object. Whatever feeling may be integrated with an object once desired, but now perceived, desire is absent. The same object, retrospectively thought of, is not desired, unless there is also an idea of it as again possible: that is, an anticipatory idea. The perceived object can be desired only indirectly, that is, only in so far as there is an idea of its continuing to be perceived. The anticipatory idea is a prime essential. While we cannot at present assign the organic basis for this peculiarity of desire, it is an indisputable fact.

Now the general conditions for the formation of an association are that the two things to be associated or integrated must be perceived or thought of in close temporal succession, or simultaneously. It is obvious, therefore, that in thinking of the cause of a desired event (the cause of obtaining a desired object), the desire is in many cases experienced in close temporal sequence or precedence: and that in thinking of a desired event, one frequently is impelled, by already established associations, to think of the causes. But in desiring an event, one is less apt to think of its effects, and when the effects occur, and must be experienced, the object is no longer desired but is retrospectively thought of. The conditions are therefore generally excellent for associating a desire with the cause of the desired event; generally not good for the association of the desire with the effects. The general spreading of desire in the line of ascending causation is, therefore, what the laws of habit formation would lead us to expect.

It is probable that the chief, although of course not the only, process through which desires are substituted is through the already formed association of cause and effect. But after a desire has been attached to an object or event through this process, the laws of habit still hold, and the new object or event may continue to be desired, independently of the original or primitive desire for the original object or event. A man who acquires a

desire for work through the association of work with food, shelter, sex gratification, or preeminence, which are primarily desired, may often acquire a permanent desire for work which persists after the primary desire has ceased. So a person who engages in social activities, or in meticulous attention to details of dress as a step towards the furtherance of a social ambition, comes to desire these things in themselves.

Primitive man, in a healthy state, shows all the nine desires listed; but if natural conditions are such that the alimentary and shelter desires are easily satisfied, further development of desires by substitution is relatively small, and culture remains in a simple stage. If food and shelter are easily obtained, the satisfaction of the parental and amatory desires are complicated only by the rivalry for mates, which introduces desire for ornament, warfare, and social activities (such as dancing) of a simple kind. Unless population increases rapidly, society soon reaches a stable state, in which desires are standardized on a permanent basis. The desires for preeminence and conformity are satisfied on the basis of warfare and the other simple activities described. In a tropical climate, with abundant food, and few natural enemies in the way of disease and deadly animals, culture apparently would remain indefinitely in this stage, as in the South Sea Islands before the advent of the white man.

In colder climates, where both shelter and food are obtained with difficulty, not only are the satisfactions of these desires made more intricate, through the introduction of many new desires for objects and processes causally connected with the satisfaction of alimentary desires, but also, on account of the difficulty in providing for wives and children, the satisfaction of amatory and parental desires is made immeasurably more difficult, and vast numbers of contributory desires, social and material, are created.[115] The creation of these desires, with the need for their satisfaction, leads to the creation of still others, and so the terrifically complex system of civilized desires arises. Modern inventions, such as steam engines, telephones, and phonographs, are made

[115]In much colder climates, as in the arctic region, conditions are still different. The extreme difficulty in satisfying contributory desires in those regions prevents their development.

under the impelling force of sex desire, alimentary desire, and desire of preeminence on the part of the inventors, and still further complicates the system. There is no greater satisfaction of desires in civilization than in the primitive culture of virgin Samoa: probably far less! But we have been forced, and force ourselves, to satisfy the primitive desires in endlessly complex ways.

In the general multiplicity of desires, it is impossible to disentangle the primary desires which enter into the different derived desires. It is clear, however, that in the vast majority of cases, our desires are derived from the primitive desire of the fifth, sixth, seventh and eighth classes. The food and rest desires, although satisfied with increasing difficulty, offer their chief difficulty in connection with problems of mating and supporting children, and it is the urge of the last two desires that multiply causes and the desire for them. In many cases, the desires for causal factors ultimately become engrossing, and "civilized" man is often so much occupied with the satisfaction of these that he does not mate at all, although he may have acquired the means to do so. The primitive sex desires have expended themselves in means, and the primary ends are ignored.

Full discussion of the development of desires, and their functions, belongs to Social Psychology, which must ultimately be founded on the basis of desires and the satisfaction of desires.

§8. Hedonic feeling.

In the discussions of feeling in the past, pleasantness and unpleasantness have received more attention than any other feelings, and have sometimes been treated as if they were the only feelings. For this reason, the term "hedonic" has occasionally been applied to all feeling, although it properly describes pleasantness and unpleasantness only. Pleasantness and unpleasantness together, as positive and negative aspects of the same factor, have even been described as "characters of sensation," on the same plane as quality, intensity, etc. This characterization has, of course been abandoned. Hedonic feelings are a common accompaniment of sensory and thought content, but are by no means invariably present.

Various causes have been ascribed to unpleasantness and pleasantness. Bringing somewhat divergent theories under one general form, we may say that the common view has been that pleasantness accompanies those reactions and organic conditions which have been in the past beneficial to the organism, and unpleasantness those which have been harmful. Particular conditions which are actually harmful, such as the effects of certain drugs, are pleasant because they are conditions which in the past have been generally produced by beneficent stimuli or activities, and the organism has not adjusted itself to the effects of the newer stimuli and activities which produce, temporarily at least, the same conditions. Painful stimulations, such as operations on the nose and throat, which may be beneficial to the organism, produce unpleasantness because in the remote past all most painful stimulations have produced harmful results, and practically none have produced beneficial results, and the organism has not adjusted itself to the quite different conditions of modern surgery.

There is, of course, a certain truth in this theory, but it does not express adequately the facts at the present time. It is perhaps more adequate to relate hedonic feeling to activities and organic conditions through desire. All activities which satisfy desires are pleasant, and all activities which inhibit or delay the satisfaction are unpleasant, that is, they produce the organic conditions (at present not definitely identified) which are experienced as pleasantness and unpleasantness. To this we must add that it is quite possible that certain types of activity which will satisfy primary desires when the desires arise, may appear in the child before the desire appears, and that these activities will produce pleasantness. This is, of course, involved in the basal conception of instinctive activities, which is that integrated reaction patterns appear in the animal antecendent to the conditions in which they may be fully exercised. Even if the play activities of the child should occur before the conscious desire for activity (we are not assuming this to be the case) these activities would produce pleasant feeling. We must add further that the laws of habit hold in regard to feeling, as in regard to all processes, and that therefore activities which have become mechanical, the desires prima-

rily connected with them having ceased to occur in them, may still be pleasant, if they were originally pleasant.

The relation of "pleasantness" to "pleasure," and of "unpleasantness" to "pain", has been the source of some confusion in the past. The terms pain and unpleasantness were, in the early history of psychology, used interchangeably, and so also were the terms pleasantness and pleasure. The later tendency was to distinguish these terms sharply, using pain for the sensation, and unpleasantness for the feeling: pleasantness for the feeling (simple) and pleasure for the emotion (complex, including pleasantness as one of its components). Since the distinction between sense data and feelings has necessarily been made less sharp of late, it may de doubted if the former distinction is useful. Unpleasantness seems to differ from pain in being less intense, and less distinctly localized: but we may well expect to find that otherwise the two states are the same. Even the "pain" resulting from stimulation of the skin in certain ways, seems indistinguishable from unpleasantness when of low intensity. The distinction between pleasure and pleasantness may, perhaps, be more useful: pleasure may indeed include other elements than pleasantness, although it is at present impossible to say just what these other elements may be.

§9. Observational and experimental work on feeling.

Attempts to study feeling which have been made in the past may be classified under the three heads of genetic, introspective and experimental.

(a) *Genetic interpretation*

The genetic study has consisted of the observation of the reactions of children, and the attempt to interpret them in terms of emotions and simpler feelings experienced by adults. This method is, of course, valid, if we have an adequate knowledge of the adult feelings, and of the expressions (actions observable by another person) which definitely indicate the occurrence of these feelings. If, for example, we knew exactly what visible, or otherwise observable reactions in a normal adult human being indicate the occurrence in that individual of a definite feeling which we will agree to call fear: and if we should find those reactions occurring in a

child of a given age under given stimulus conditions, then we could say that the child under those conditions experienced fear, Unfortunately, the most essential reactions in a feeling of this kind are those (visceral) which are not directly observable except by the individual himself, and our knowledge of the other reactions (striped muscular principally) which invariably accompany these essential visceral reactions is far from adequate. On this account, the genetic studies which have been made have resulted in little but confusion. In the most recent studies of this sort,[116] the reactions of children to various stimuli: auditory, visual, etc., have been carefully observed, and it has been found that infants are startled (show violent general contractions of the striped muscular system) when a loud, high-pitched sound stimulates their ears; and that they may cry. These observations are useful, and the results valuable for further reference when the actual results are set down without addition. But, unfortunately, it is further inferred that these infants experienced "fear," although the assumption is somewhat clouded by the "behavioristic" principle that one cannot speak of that which the person or animal under scrutiny experiences, but only of that which the *observer* experiences. The inference is at any rate made, that the infant has the total essential reaction which an adult has when he is commonly said to experience fear.

Now we know that the general muscular reactions which were observed in these infants may be shown by an adult who is merely startled, and who has no fear in the usual sense of the term: and also that these general reactions and the crying reaction may be shown by adults in cases where there is neither startle nor fear, but merely pain. Hence we have no grounds for assuming, from these simple observations, the existence of fear in these infants at all. The observations are interesting studies of the behavior of infants under definite stimulation conditions, provided nothing is ascribed to them but that which is actually observed: but they do not bear on the problem to which they have been referred, nor do they give us as yet any important information concerning the

[116] "Behavioristic" work is here classed as genetic. Behaviorism is, in fact, the later form of genetic psychology, its general methods being those of the earlier genetic school, with the addition of more precise use of apparatus.

feelings of either adults or infants. This criticism may be extended to cover all the genetic work which has been done on the problem of feeling. The genetic method can be usefully applied here only after we have acquired much more information on the subject of feelings than we now possess.[117]

(b) *Introspective work.*

In the strict meaning of the term, all work on feelings must be fundamentally introspective, or must be based on thoroughgoing introspective observation, since the feelings are just those contents which can be observed only by the individual who has them, and who must therefore observe them by "looking into" his own organism. The term introspection has, however, come to have a different meaning, and does not signify observation through the somatic and visceral afferent neurons, but signifies apparently a peculiar method of observing objects of all kinds, whether through the external or the internal senses. Just what this method involves in theory, and the assumptions on which it is based, are not clear to those who do not belong to the "introspectionist school", but in practice, the method very often seems to come down to *the observation of all content, so far as possible, which is present during any given period of time.* This method is sharply opposed to the experimental method, which always aims to narrow the observation at any given time to a small group or detail of content, selected in advance for observation, withdrawing attention for the moment from all other content.

Introspectionist attempts to study feelings have resulted in considerable masses of observations on feelings, organic sensations, kinesthetic data and thought contents, but from all these detailed observations there are no conclusions obtained as to any general principles or facts of feeling. The observations remain mere histories of the different sorts of reports which different observers were able to make under different and similar conditions. This is perhaps the outstanding virtue of the introspectionist school in its work on feelings: that no general conclusions have been made.

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[117]The acquisition of data on the growth and development of children, as a purely "behavioristic" or physiological study, is, however, of great importance, and as more information is obtained concerning the feelings, this data may become material for the application of the genetic method.

(c) *Experimental work.*

One of the hypotheses concerning feeling which was formed in the early history of the subject was that some feelings, especially pleasantness and unpleasantness, were directly connected with the dilation and contraction of the blood vessels. This hypothesis was formed even before the visceral hypothesis of the feelings was elaborated, but both Lange and Sutherland, in outlining the visceral hypothesis, gave the chief role in all feeling to the blood vessels. Much experimental work has been done on this point, with disappointing results. It has been found that all changes in feeling are accompanied by changes in the distribution of the blood in soma and viscera, and changes in blood pressure: but it has also been found that similar changes accompany all conscious activity, and even reactions which are not conscious. This might be taken as indications that all reactions produce changes in feeling: a conclusion to which all considerations predispose us. But no connection has been found between any specific feeling or type of feeling and any specific change in the vascular system. Fear always produces a rise in systolic blood pressure; but so do joy and strong interest. Painful states, and pleasurable states, may either produce swelling or contraction of the arms and legs through increased blood supply to these members. Undoubtedly there are definite connections between feelings and vascular conditions, but the latter are so complex that no simple measurments will suffice to reveal them. Dilation of the capillaries in the arm, for example, may at one time be shown by increased volume of the arm, the blood being forced into it because the blood-vessels of the viscera are constricted. Yet at another time, the same relaxation of the capillaries in the arm may be accompanied by decreased arm volume, because the visceral blood-vessels are also relaxed. It is not to be supposed that the vascular line of experimentation on feeling is infertile, but rather that it needs to be more highly developed.

More recently two interesting lines of experimentation have been opened up by Washburne and Cannon, and have been further worked upon by Carlson and other experimenters. It has been found by these experimenters that the exciting emotions produce, or are accompanied by, a marked increase in adrenin, the internal secretion of the adrenal glands; and an increase in the blood-sugar

(glycogen) which is secreted by the liver. The increased adrenin, as well as glycogen, has been experimentally found in cats which have been made to show signs of fear and rage by being threatened by dogs, and also in animals excited by pain, and by being bound in unusual positions, although without any painful stimulation. Increased glycogen has been found in human beings after various exciting experiences, such as playing or watching football, and even after taking college examinations. The finding of increased glycogen in healthy reactors is itself a proof of increase in adrenal secretion, since the glycogen increase is due to the stimulation of the liver by increased adrenin content in the blood. Adrenin has also the effect of increasing the sensitivity of muscle, and also of neutralizing the effects of fatigue products, or preventing their usual effects. In both ways adrenin facilitates muscular activity, as well as promoting those glandular activities essential for prolonged muscular activity. The exciting emotions, therefore, may be understood as preparations for strenuous work. The phenomenon of "second wind" is believed to be due to the effect of adrenin on fatigue toxins.

Experiments on hunger have been made to test the hypothesis that hunger is dependent upon contractions of the empty or partly empty stomach. In these experiments, the reactor swallowed a thin rubber bulb, attached to a rubber tube, connected to a recording tambour, writing on a kymograph drum, so that the changes in pressure within the stomach may be recorded. These changes in pressure are due to breathing, to irregular changes in tension of the diaphragm and abdominal muscles, and to changes in the contraction of the stomach itself, but the changes due to the latter cause can be discriminated from the other changes. Some reactors have been found to experience "hunger pangs", or "hunger pains", which occurred rhythmically, with short periods of relief intervening. When these reactors are allowed to record on the kymograph, by pressing a key, the onset and cessation of the "hunger pangs", it is found that the beginnings and ends of the pangs are almost simultaneous with the beginnings and ends of the stomach contractions. The contractions in typical cases last from twenty to forty seconds, with intervals between ranging from a few seconds to a

minute or more. The whole series may last from six minutes to two hours and a half.

From these observations it has been argued that hunger is caused directly by the contractions (or perhaps *is* the contractions), of the stomach. This inference is unacceptable, however, for the following reasons: (1) Alcohol, in moderate quantities, inhibits the rhythmic stomach contractions completely (the quantity contained in an ordinary cocktail, or even a less amount inhibits the rhythmic contractions), but it does not, as a large number of persons can testify, inhibit hunger, although it may stop the "pains" of hunger. (2) During certain periods of starvation, by the methods of recording above described, hunger was found to be present when the contractions were absent. (3) Some reactors, who experience "hunger" in a definite form, never have the "pangs" or "pains" described by the reactors of Washburn and others. In these cases the hunger is a continuous state, quite comparable to thirst in its rise and course. This hunger is not mere emptiness, faintness, nausea, or any of the other feelings which are often associated with it, nor is it "desire for food", but a distinct feeling *sui generis*. In many cases, hunger is distinctly pleasant, and not combined with any unpleasant or painful feeling which might lead to its being called a "pain" or "pang". (4) Peristaltic contraction of the stomach occurs during digestion, and other contractions of a violent type occur in nausea; but hunger does not occur with these, although hunger, if long continued, may pass over into nausea. It is difficult to see how these contractions can differ so in effect if hunger is caused by contractions.

The situation in the empty stomach during "hunger pains" may perhaps be illustrated by an experience which many persons have had, following a burn in the palm of the hand. If the burned area is mildly smarting, closing the hand strongly may cause a considerable increase in pain, and relaxation is followed by temporary relief: but the pressure is not the primary cause of the smarting pain.

The experiments of Washburn, Cannon, Carlson and others do show that hunger is probably a local condition of the stomach, which is intensified by stomach contractions, and made painful

thereby in some cases; but they show also that the contractions are not the primary hunger or condition of hunger.

These experiments so far suffer from lack of psychological analysis, leading to an identification of the characteristic hunger with the pain, or pain and strain, which accompany it in extreme cases. The hunger, strain, pain, emptiness, faintness, nausea, and desire for food must be clearly distinguished from each other, in final experiments.

§10. Feeling and habit.

It is clear now that feeling has two sources. It is in part the result of local or systemic changes of a general nature, and it is in part the immediate result of reactions. Pathological changes in any of the organs in which receptors terminate or in the organism generally may produce modifications in feeling: and so likewise may non-pathological changes such as those occurring in fatigue and the elimination of fatigue products. Broadly speaking, the basal condition of feeling is the condition of the somatic and visceral tissues. The influence of these conditions is especially obvious in moods: but it is to be remembered that in all feeling, the systematic condition is just as influential. The effects of reaction are produced in the tissues in accordance with the conditions existing therein, and the capacities for changes dependent on those conditions.

Independent of the reactions of the moment, there is a basal feeling-condition at any time. The reactions further modify this feeling condition, producing the relatively sudden changes which we identify as the beginning, or the cessation, of this or that specific feeling. The reactions follow the universal laws of habit formation, and we find, therefore, a large factor of habit involved in the rise and fall of the feelings. We admit that from the individual's beginning there are certain inherent tendencies to respond with specific feeling-reactions to specific stimulus patterns: to have pleasure, through responses to certain stimuli, and pain through response to certain others: but we must also admit that these tendencies are continuously modified by experience. We acquire tendencies to respond with pleasure to stimulus patterns not originally pleasurable: and we lose the pleasure response to other patterns which originally released that response. The same is true

of all the feelings, simple and complex. In the total mass of feeling-response of the individual, there is very little that is really "instinctive": the original tendencies have been so recombined and modified by learning that the resultant reaction-patterns are as thoroughly "acquired" as any group of reaction-patterns in the organism.

In regard to the greater number of the nameable emotions, this is so readily understood and so generally known, that little exposition is necessary. The tendencies to become angry, or afraid, or elated, or sad, upon this or that stimulus pattern, are admitted to be habits, fixed by recency, frequency and vividness, as are all habits. The importance of habit in the specifically sexual feelings, and in the various feelings in which pleasure and disagreeableness are the conspicuous elements is perhaps not so generally understood. But these, just as much as the first named feelings, are really matters of habit. Situations which arouse strong sexual desires, and the complex of attendant feelings, in one person, do not arouse the same feelings in another, although the second person may have just as strong feelings of this class under other circumstances. Any person under the influence of habit formation, may come to have sexual feelings under circumstances in which he formerly did not have them. The ease with which sexual perversions are formed, the striking effect of incest prohibitions, and the rapid changes in sexual tendencies in persons brought up under strict "moral" inhibitions when subjected to more "lax" conditions, are striking exemplifications of the importance of habit in this realm.

The influence of habit in connection with the feeling complexes in which pleasure and unpleasantness are present is clearly indicated in the realm of aesthetic appreciation.[118] Color combinations

[118]The quickly varying styles of women's attire present several interesting problems as to the relation of hedonic feeling to "principles of beauty" and to "conventions." It is evident that many women derive pleasant feeling from the wearing of costumes while they are "in style," which when "out of style" are admitted by these same women to be ugly. It is possible that "style" and "beauty" are completely divorced as regards the effect of costume on women, but the questions as to whether the effects of one may completely counteract the effects of the other: whether the two effects may coexist: whether generalized hedonic habits (principles of beauty) occur in woman's appreciation of her costume and ornaments; or whether only particularized habits (conventions) occur in this sphere, are yet to be answered. It has even been alleged that real aesthetic appreciation is an exclusively male function, and that women's appreciation of beauty is a matter of convention only.

which in one decade are generally considered to be disagreeable or unpleasant, are in another decade considered "beautiful". Tone combinations which are disapproved often come to be approved. The rise of the music which includes much dissonance or discord illustrates the progress of habit formation in this field. Almost all hearers accustomed to the smoothly harmonic music of the older schools, whether popular music or music of the "better" grade, find at first the modern "good" music of the dissonant sort as well as the popular jazz which corresponds to it, quite disagreeable. But after such music has been heard repeatedly, it begins to arouse feelings in which satisfaction and pleasure are predominant.

CHAPTER XVI

THE EMPIRICAL SELF OR "ME"

One of the most obvious distinctions in the content of experience is the distinction between the *self* and the *not self,* between *me* and the *remainder of the observable world.* This distinction in the content must not be confused with the distinction between the content and the ego, I, or knower, and does not involve the conception of a "soul", or "spirit".

In our survey of experience, we have found the content to be analyzable into sentienda, relations and feelings; and have found further that the distinction between feelings and sentienda is purely one of convenience. Unless we can find a *me,* or objective self *sui generis* which somehow accompanies, pervades, or is experienced with these contents, we shall have to conclude that the known self is also composed of these same elements. Actually, no unique self-content is discoverable, and careful analysis shows, as we might expect, that the empirical self is a synthesis of all the sentienda and feelings which together make up the experienced organism. In other words: the fundamental "me" is the experienced body (soma and viscera), as it is experienced through the functions of my visceral, somatic and external receptors. This is the central self, or the central part of the self. But the total self includes more than this mass of content and its interrelations: it includes also the relation of these contents to other, outer contents. Family relations, social relations, and business relations, for example, tend to become relations with the self, which, metaphorically speaking, enlarges to include them. The self of another person is, for my experience, his body and its conduct in so far as I can experience it. My experience of your self is limited, therefore, to the processes dependent upon my visual, auditory, olfactory and cutaneous receptors. I cannot perceive your feelings: that part of your self is your own private property in so far as perception is concerned. Yet even this privacy is a limited one,

for another person may, in certain cases, experience your feelings as thought-contents: *i. e,* I may *think of* them.

Even the perceptual sharing of your feelings with another observer is not inconceivable. If one of the afferent nerves whose peripheral terminals are in your arm muscle could be dissected out, and the terminals transplanted into the biceps of another person, leaving the connection of the nerve with your spinal cord intact, you could have the feeling of this other person's muscular contraction. Through similar crossing over of autonomic afferent nerves from one person to another—a surgical operation which is conceivable, although perhaps not practicable—the one person might literally experience (perceptually) the feelings of the other. The impossibility of your actually perceiving the feelings, and hence the inner self, of another person is therefore not due to any strange difference between these contents and other contents, but solely to the arrangement of your receptors, which precludes their being stimulated by the other person's feelings. Your inability to experience another's self, as he experiences it, is no more mysterious than your inability to perceive a landscape when your eyes are closed.

The self of one individual, in so far as it is experienced by another individual, or in so far as it is estimated by another, is properly designated the *personality.* There are, of course, other uses of the term, but this usage is customary and preferable.

In the self, there are certain factors which are more important, more fundamental, than others. These essential factors are the ones most constantly present. Here we find the essential relational factors involved in the "me". It is the persistent presence of these self factors, amidst the more transitory external factors, which distinguishes them from these external factors and gives the more constant reference to the ego which characterizes the "me". We may get away from any of the external objects, but we never get away from or shut out the feelings of the body. The more adventitious feelings and bodily processes are fused with the more persistent mass because, no doubt, of their qualitative likeness and spatial localization. These adventitious feelings, however, are not felt to be the essential nature of the self, but changes,

or modifications of the self. Or, we may say, they are certain phases, or aspects of the self.

This view of the feelings and emotions as modifications of the self, although an empirical one, is essentially involved in the philosophy of Spinoza, who prefigured in his speculations the theory of the emotions formulated two centuries later by James and Lange.

Psychic individuality, or self-hood, therefore, means more than mere capacity for experience. It means the existence of a specific, although complex, content which is persistently present; which, although it changes its total character, changes slowly; and hence is the standard against which all other content is measured. The self forms accordingly the basis for the perceived continuity of the ever-changing content. Its rhythmic variations with the solar day and physiological condition serve as the clock of consciousness. When hungry, the idea of the normal steps for obtaining food are brought up through normal association. In the morning, the recurring associations with the morning state of the self bring up the proper ideas for that time of day almost unfailingly. The intricate system of associative nexus which bind past experiences together and make our relatively orderly mental life possible might be supposed to be controlled in some other way, but as a matter of fact, they *are* controlled by the particular associations of this bodily self with the other factors in the manifold.

The mass of habitually experienced content is the fundamental self. Even habitually experienced thought content may become a part of the total self. "As a man thinketh, so is he", is trite but largely true. But the habitual trains of thoughts are determined to a large extent by the feelings: and so in the healthy individual, the self, including all these factors, is a rather coherent mass of content.

In many cases an apparently normal individual possesses a double self. The church-going business man, for example, may really think admirable thoughts on Sunday, and these thoughts may be allowed to find expression in suitable action. On other days he may think only of business, and his actions may be quite at variance with his Sunday doings. It is quite probable that in such a case he builds up a double set of affective or inner

selves, one of these selves being associated with each of the thought-complexes. The evidence for this assumption is found in the fact that his facial and bodily expressions change with his change of character, and give us reason to suspect more profound organic modifications. Certainly, he has two sets of emotional habits. He really is not a hypocrite, in an ethical sense, but is a diseased person: a monster with two selves.

There are an indefinite number of possible principles of bifurcation of the self, and these bifurcations may be incipient or thorough-going, that is, they may affect little more than the habits of thought, or may affect the mass of organic processes. A man may be pure-minded at certain times, and lewd at others; he may be a buoyant optimist and a downcast pessimist; and so on *ad infinitum.* And any of these divisions of self-expression, by the gradual formation of associations, may become a cleavage affecting practically the whole personality. In some cases there may be three of these fractional personalities, or even more.

It is probable that none of us is completely free from the taint of divided selfhood: but most of us need not fear any disastrous developments. The dangerous cases are those in which one division of the self has long remained an inner core of feeling, without the outward associated expression. An individual, for instance, may give rein to the moral member of his team of selves, and allow the lewd side to express itself only at the infrequent times when he thinks he is safe from the observation of his associates. In such a case, some change in the bodily condition, deeply stirring the whole self, may give the "repressed" self its chance, and it may flare up, perhaps suddenly, and become dominant. In extreme cases the sets of ideas constituting the thought side of the previously dominant self, and the other groups of ideas associated with these, are completely lost, and hence the patient not only evinces a seemingly new personality, but actually loses the memory of years of his life. These sudden changes are called *alterations of personality,* and in the cases where there is repeated change from one personality to the other or others, the terms *alternation of personality* and *alternating personality* are applied.

APPENDIX I

MENTAL DEFICIENCY AND MENTAL DISEASE

§1. Abnormal psychology and mental inefficiency.

The detailed discussion of mental disease and mental deficiency belongs to the extensive topic of abnormal psychology and to psychiatry, not to an introductory text of general psychology. It is important, however, that the student of general psychology should have some conception of the nature of the diseases and deficiencies which are most commonly described, since he necessarily will meet with references to the names of these conditions, even if he does not study abnormal psychology.

The classifications and descriptions of mental diseases are largely the work of psychiatrists, who officially deal with the care of mentally diseased patients. Unfortunately, there are many systems of psychiatry, differing much in their conceptions of the natures and origins of mental diseases, and in their classifications and descriptions. Hence we cannot present here a sketch which will represent a concensus of opinion of psychiatrists, but can merely present certain matters concerning which the differences of opinion are relatively small. We shall approach the subject rather from the point of view of abnormal psychology, which is primarily interested in the analysis of the abnormal mental processes, and in their comparison with normal processes.

We may distinguish between normal and abnormal mental processes in either of two ways. First, we may consider the whole range of variations in some type of response, and measure the range of variations. We may, for example, measure the simple auditory reaction times of many men, and when we have obtained the average time for each man, we may find that these averages range from 90 sigma to 250 sigma. In such a group, we would find relatively few individuals with averages lying between 90 and 100, and relatively few averages between 220 and 250. We would find a somewhat larger number of averages between 100 and 110, a still larger number between 110 and 120, and further increases

with each decade until the maximum would be reached between 140 and 150 perhaps; from which point on, the numbers would be found to decrease.

We might then assume that a simple auditory reaction time between 140 and 150 is "normal," and that reaction times lying between 90 and 100 and between 220 and 250 are decidedly "abnormal." The 90-100 group in this case would be designated as *supernormal;* the 220-250 group as *subnormal.* But from that point of view we would not be able to define sharply the limits between normality and abnormality. A reaction time of 120, for example, would be classed as "normal" or "abnormal" according as we should arbitrarily draw the dividing line. In general, we would define the "normal" as that which is of relatively frequent occurrence; but "relatively" is a vague term.

Similar determinations might be made for accuracy of response; for speed and precision of learning; and for any other mental processes. After establishing norms for the total range of mental processes, we might, theoretically, construct from these norms the definition of the "normal mind."

The use of the terms "normal" and "abnormal" in the way just described is of little importance or convenience. For practical purposes the terms are employed in a different way.

Since we are dealing in psychology with the adjustments of organisms, we distinguish those adjustments which are sufficiently efficient for the needs of the individual from those which are definitely inefficient, and call the first *normal,* the second *abnormal.* The distinction is therefore one which rests primarily on practical ends, and not on the psychology of the animal as an individual.

The man whose simple reaction time to an auditory stimulus averages between 90 and 150 sigma is sufficiently quick in adjustment for all the requirements of life. The man whose average lies between 200 and 250 is too slow for many requirements. The first man is therefore rated as "normal" in reaction time; the second as "abnormal." The exact limits between the normal and the abnormal must be decided on practical grounds.

Abnormal psychology, as the term is broadly used, deals with adjustments which are abnormal in the practical sense. The field of abnormal psychology is broad, since every individual is at some

time abnormal in some of his responses; and a great many individuals are consistently abnormal in one or more respects. In a narrower sense, abnormal psychology deals with those abnormalities which are systematized, that is, which occur in characteristic groups.

A systematic group of abnormal responses which is congenital is designated as *amentia*. Amentias are incurable. Other groups, which usually arise later than childhood are called *mental diseases*, among which are the dementias. Some mental diseases are intermittent in their occurrence; others become steadily worse; still others may disappear in the course of time. Psychiatry, in the strict sense, deals with the care of the patients suffering from these disorders, and the attempt to cure or alleviate them.

Mental diseases are customarily classified as *psychoses*, and under this heading there are many systems of sub-classification. Certain diseases, which, from the psychologist's point of view are as "mental" as are any of the admitted psychoses—in fact, more emphatically mental in many respects—are classified by some psychiatrists not as mental diseases (psychoses), but as *nervous diseases* or *neuroses*. Strangely enough, these neuroses are precisely those disorders (hysteria, neurasthenia, psychasthenia) for which no neurological bases or causes have been discovered or even strongly indicated. These diseases have therefore been further designated as *functional neuroses*, and contrasted with the psychoses which are assumed to be due to structural defects or degenerations in the nervous system, or to the effects of toxins or other chemical substances upon the nerve cells.

The origin of this misleading terminology is complicated, being in part due to the old metaphysical theories concerning the mind; in part to the fact that the neuroses are in general curable, while the other psychoses are not; and in part to the very fact that the assumed neural bases for the neuroses were not even conjecturally definite.

Of late, there has been a tendency to drop the term "neurosis," and to classify all mental diseases as psychoses; and there has been also a variant tendency to substitute the term *psychoneurosis* or *neuro-psychosis* for "neurosis." This latter tendency is unfortunately confusing, since the term "psychoneurosis" has

earlier had just the opposite meaning, namely, the psychoses exclusive of the so-called neuroses.

It is practically useful to separate the psychoses from the neuroses in our discussion, while understanding that both names are without intrinsic significance, and that they might better be designated as "Group A" and "Group B."

§2. The psychoses.

Psychoses vary widely in degree of affliction, from those which are so light as to pass the ordinary observer unnoticed, to those which are so grave that they not only are noticeable to the average man, but require special care or restraint. To the latter type of case only is the term *insanity* properly applied, a patient not being insane, strictly speaking, so long as his trouble does not necessitate the taking of specific action towards it by other people.

The typical psychoses, that is, those which occur in characteristic forms and have been definitely described, are: Dementia praecox, paraphrenia, paranoia, maniac-depressive psychoses, paresis or general paralysis, senile dementia, epilepsy, and various alcoholic and drug psychoses. Many variant forms of these diseases have been named and described by psychiatrists, but those above named are the types on which there is substantial agreement, although the agreement is far from complete.

Senile dementia is a form of deterioration of response which occurs in old persons, usually not before the age of sixty. It may be described as an exaggerated form of the type of mental decay which commonly occurs in old age; but such description is not quite accurate. Senile dementia is characterized by a lowering of integration, and by a breaking down of many specific integration tendencies previously established. Attention, for example, is not readily maintained, and does not reach a high level. Perceptions are inaccurate, and both illusions and hallucinations increase in frequency of occurrence and in disturbing power as the disease progresses. Loss of memory, and occurrence of false memories are important characteristics, and delusions (*i. e.*, systematic false thoughts together with false perceptions of the environment), result.

The delusions of senile dementia may take the form of belief

on the part of the patient that he is being persecuted; or the form of groundless self accusation; or of vast self-importance; or one of many other forms. The patient is unable to learn, and has an exaggerated intolerance for new conditions and new ideas. Self, and the ideas of self, become unduly prominent and persistent, and normal reactions to other persons become lessened. These conditions we commonly describe as selfishness, egotism, and disregard for the rights of others. Customary restraints on the stronger habitual tendencies (as of sex) are lessened, resulting in attempts at rape, indecent exposure, and other antisocial actions. The patient may be extremely hard to manage until tendencies towards muscular weakness and nervous exhaustion induce a condition of helplessness.

Dementia Praecox, sometimes called schizophrenia, may occur at any time of life, even in infancy, although characteristically showing itself near the period of puberty. It is characterized by hallucinations and illusions, but more fundamentally by emotional deterioration. Normal desires and interests, even those of sex, are weakened, and pride and ambition are lacking. The patient may fall into a state of profound apathy, or he may be very irritable. Thought processes are er[illegible] and illogical. Attention is impaired, especially in the apathe[illegible]. The retention of what has been learned before the onset of the disease is not affected, except in late stages of long standing cases. Further learning is however made difficult.

Normal coordination of response is lessened in dementia praecox; in other words, volitional and purposive acts become reduced in frequency, in speed, and in accuracy. There is a corresponding increase in uncontrolled automatic activity, such as grimaces, laughter, and other impulsive acts. Certain reflexes, such as the knee-jerk, may be heightened, although they are sometimes lessened. One manifestation of the lowered integration, which is sometimes mentioned, is a tendency towards masturbation in the early stages of the disease, but this is also characteristic of the other dementias and of amentia. Eventually a condition of stupor may be reached, with the maintenance of fixed attitudes of the body and positions of the limbs.

Paraphrenia is similar to dementia praecox, but develops later

in life, usually in middle age. Its chief characteristic is the existence of delusions which are well systematized. Paraphrenia passes through four well marked stages. In the first stage the patient is either emotionally depressed, or extremely irritable, with characteristic hypochondriac delusions of fictitious diseases. The second stage is paranoid, with delusions of persecution. In the third stage the delusions are of grandeur. The patient may identify himself with an important historical or allegorical personage, such as Julius Caesar or the Pied Piper of Hamelin. The fourth stage is that of dementia proper (general mental inefficiency, affecting memory, perception, attention and motor control), but with comparative freedom from the delusions which mark the preceding stages.

In *paranoia* there are highly systematized delusions, characteristically of persecution and grandeur, but with no other significant mental deteriorations. The patient does not, however, confuse his personality with that of some other person, but is thoroughly consistent. If he believes that he is a great inventor, he works persistently at invention. If he believes that he is a great religious teacher, he is active in religious propaganda. If he believes that an important lady is in love with him, he seeks persistently to make love to her, or to flout her, as the case may be. The delusion is, in short, an imaginative expansion of his own personality.

The consideration of cases of paranoia sometimes leads theorists to believe that every serious advocate of something of which the theorist does not approve is "paranoiac." This results in two absurdities: all who have been responsible for advances in civilization are classed as paranoiacs, and the theorist is himself convicted of the same disease, through his taking his own beliefs so seriously. There is no real likeness between paranoia and devotion to a cause, nor between paranoia and a reasonable belief in one's own worth.

Melancholia and *Mania* are recurrent forms of mental disease; that is, they are diseases which may occur periodically in the patient. These conditions are primarily emotional, but in their more pronounced forms they are accompanied by various perceptual and ideational defects: impaired accuracy of perception,

of memory, and of judgment. In the most severe forms, hallucinations and delusions occur.

Melancholia is emotional depression, in which the patient is lethargic, uninterested in his surroundings, and has lessened desires. The condition resembles the emotionally depressed type of the first stage of paraphrenia, but without the hypochondriac delusion of disease. Gloom possesses the patient, and his thoughts correspond to his emotional state, taking extremely pessimistic forms. His delusions take the form of sin, shame, and defeat. In *mania*, on the other hand, the patient is elated, excited, and in extreme cases delirious with joy, anger, or some other excited emotion. His thoughts are rapid and his words fluent, and his imaginative powers are at high tide. This is the "lunatic" of the popular conception; the man who "raves."

Melancholia alone may recur periodically, with intervening periods in which the patient is apparently normal. Mania alone may also be recurrent in the same way. In other cases, mania and melancholia alternate, the patient passing directly from the one to the other. In still other cases there are normal or "lucid" intervals between the alternating abnormal phases. These latter forms constitute the true *manic-depressive insanity.*

Manias and melancholias of non-periodic form may occur in alcohol psychoses, drug psychoses, or other psychoses of specific causation. These are not classified with the manic-depressive type.

Paresis, dementia paralytica, or *general paralysis of the insane,* is a disease of fairly rapid course, beginning usually in middle age. It includes various disorders of sense perception, thought and attention, beginning sometimes with delusions of grandeur or of insignificance; or with excitement, melancholia, or hallucinatory states. It progresses to disorders of memory, general motor incoordination, and muscular weakness, and ends in two or three years in the death of the patient. There are sometimes definite attacks of paralysis resembling epileptic fits, but usually without convulsions. Hypochondriac delusions of sin and disease sometimes occur.

Paresis is the one mental disease whose cause is definitely

known. It is always a result of syphilis, beginning, in some cases, years after the syphilitic infection.

Epilepsy is a disease characterized most strikingly by what are popularly called *fits*. For some hours, or even days, preceding a "fit," the patient may have warnings in the shape of emotional disturbances and disturbances of sense perception. He may be restless or excited or depressed or morose, or he may have fear or apprehension. He may have hallucinations of one or more of the senses. His imaginative processes may be unusually rapid and vivid. There may be jerking, trembling, or other uncontrolled movements of a few or many muscles. In many cases, immediately preceding the "fit" there is a "warning" or "aura," consisting of a peculiar visceral or somatic feeling, sometimes accompanied by motor signs.

The fit, in severe cases begins with strong contraction of the muscles and the patient falls unconscious. Sometimes he utters a shriek, or more often a gutteral cry. Then follows, after a few moments, a period of alternate relaxation and contraction of the muscles; the patient bites his tongue, jerks his arms and legs, and contorts his body. Following this, the patient becomes quiet, with muscular relaxation, remaining unconscious for a varying time.

There are lesser fits or seizures, in which the muscular signs are less severe, and the patient may not fall, although he may lose consciousness. In some cases, even the loss of consciousness does not occur; the patient is merely "dizzy" for a brief period.

In other cases, the seizure takes the form of a complete loss of consciousness, with no definite external sign. During these "absences" as they are technically called, the patient may continue automatically the details of his occupation, or may go through more complicated actions, even journeying some distance.

In certain cases, the epileptic attack takes the form of violent, maniacal activity of a coordinated sort, in which brutal crimes may be committed. In still other cases, the seizure is a mood of great exaltation and pleasure, with vague delusions of grandeur: the "ecstasy" of the mystics.

After many epileptic seizures the patient usually begins to show the perceptual and ideational symptoms of the dementias; but in his early history, he is "normal" in the periods immedi-

ately following recovery from the seizures. Nothing is definitely known about the cause or causes of epilepsy, although various theories have been advanced.

In addition to the types of psychoses above described, there are various systematic mental abnormalities due to alcohol, morphine, and other drugs; and a group of "symptomatic psychoses" due to febrile conditions, over-activity or under-activity of the thyroid, parathyroid, and other ductless glands, and to diseases of other visceral organs.

True psychoses are in general not curable, although some cases of manic-depressive insanity, and perhaps some of epilepsy improve under good living conditions. It is claimed, however, that in persons who have hereditary tendencies to mental disease, the development of the disease may be prevented by protecting the patients from trying and exhausting influences, if such protection is given before the abnormalities become established.

The manic-depressive type of insanity, in persons predisposed to it, is apt to appear at times of emotional stress. Hence in women, the relative frequency of its appearance at the three emotional peaks of puberty, marriage, and childbirth.

§3. The neuroses.

The neuroses include a wide range of mental disorders, of which the well marked types are hysteria, neurasthenia, and psychasthenia. The neuroses, we assume, in accordance with the general assumption of the relation of mind to the organism, involve improper functioning of the nervous system, just as much as do the psychoses. But this is purely a psychological assumption and the neuroses must be considered from the strictly mental side, since no neural abnormality has as yet been found in these cases. There are many theories as to the causes of neuroses, and many and divergent types of medical treatment based on these theories. All of these forms of treatment have some success in alleviating the disorders; and none of them has such large success as to justify the belief that any general causal conditions have been discovered.

Hysteria, or *pithiatism*, shows itself in various forms. In severe cases there are *crises* or "attacks," somewhat similar to

the epileptic fits, but having a much wider range of variation. The patient may become cataleptic, *i. e.*, have muscular rigidity without falling, and may maintain a fixed attitude for a long period of time. Or he may exhibit various movements, sometimes of a highly excited sort. Hysterical laughter is but one type of such movements.

In many cases there are not definite crises; but there are various abnormal reaction tendencies, called *stigmata*, present in all cases.

The stigmata of importance all fall under the general head of dissociation, or fragmentary integration. The various units of the nervous system function normally as units, but some arcs function without being integrated into the general system. On the perceptual side this causes anesthesias of various sorts: anaphias, anacusias, athermias, analgesias, and anopsias. A certain part of the retina, for example, may be anopsic; then the patient cannot see anything the image of which falls on that part of the retina; yet stimuli to that part of the retina may produce definite response movements which are apparently unconscious. An extreme illustration of this sort of anesthesia is furnished by the patient of Janet who was apparently anaphic and analgesic over one-half of her body. She could not perceive pain or tactual impressions on that side, yet when instructed to say "yes" if she felt a pinch, and "no" if she did not feel it, she responded "no" every time she was pinched on the "anesthetic" side, although her eyes were closed and she had no warnings but the pinches themselves.

The anesthetic areas, on skin or retina, in hysteria, are not really functionless; and these areas are variable, an area which is anesthetic at one time being normal at another. In other words, the afferent nerve current from these areas is sometimes included in the general nervous integration, sometimes not. In some cases, the behavior of the patient seems to indicate that the neural transits which are not integrated with the general system, are integrated with each other in a smaller system.

Amnesias also occur in variable ways in hysteria; what is forgotten at one time may be remembered at another. In the case of hysterical amnesias, the neural mechanisms for the recall are

not absent; it is possible that the recall-transits may even occur, but are not integrated with the general system. In cases in which perhaps a second, lesser, integration system is set up, it may include thought-processes as well as perceptual processes.

There are many other characteristics of hysteria. The patient is easily hypnotized; he is subject to hallucinations of a vivid sort; but not to delusions of a systematic sort. Of the actual causes of hysteria we know nothing past dispute.

Neurasthenia, or "nervous exhaustion" is marked by a constant feeling of fatigue, and by diminished energy, and diminished resistance to depressing factors of the environment. There is increased tendency for the arousal of unpleasant feeling by sensory stimulation, hence the patient shrinks from loud sounds, bright lights, etc. The sensory mechanism is not hypersensitive, but the feeling effect is abnormal. Attention is affected, not by decrease in the relative integration at any moment, but by increased variability, so that sustained attention is difficult, and the integrations are subject to disturbance by slight sensory stimulations; in other words, the patient is easily distracted. Hence, he learns with difficulty, and quickly forgets what he learns. Insomnia and digestive disturbances are usual features of neurasthenia. The emotional moods tend towards depression and melancholy. There is no fragmentary integration as in hysteria, and no tendency towards delusions or hallucinations. The failure of previously established muscular coordinations characteristic of dementia is not present in neurasthenia. Cure is possible, through rest, proper nourishment, and relief from strain and worry.

Psychasthenia is a neurosis which is more serious than neurasthenia, and is characterized by excessive fears (phobias) and obsessions, with feelings of failure, inadequacy, and hopelessness. Sometimes the patient feels that the whole environment is unreal. The phobias take the form of fear of darkness, fear of disease or of death, fear of the opposite sex, etc., and are persistent and gripping.

Hypochondria, a form of which has been indicated above as characteristic of the early stage of *paraphrenia,* has been described by some psychiatrists as occurring in independence of other psychoses, and is therefore in most cases classed as a neu-

rosis. These cases are characterized in their early stage by abnormal vividness of visceral consciousness, usually including the contents of aches, burnings, crawlings, and other disagreeable conditions of various organs, although physical diagnosis shows no affections of the organ concerning which the hypochondriac complains. The patient often believes that he has some disease, or combination of diseases, responsible for his disagreeable experience; or he fears excessively the contracting of disease, of catching cold, etc. He is afraid to drink, dreading germs in the water; he is afraid of kissing for similar reasons. Some patients keep detailed records of their symptoms: others read extensively in medical accounts of the diseases which they fear. Others indulge freely in patent medicines, chiropractic and other mechanical treatment, or in psychoanalysis and other "mental cures."

In the course of time, the bodily functions of hypochondriacs do show pathological changes. The skin may become dry, or excessively moist: constipation or urinary troubles become chronic: sexual impotence or irritability becomes chronic; or the secretions of the glands become excessive or scanty; and so on. How far these effects are results of the long continued mental process; and how far the mental processes are due to the physiological in the first place, medical diagnosis is not sufficiently refined to determine.

§4. Amentia, or mental deficiency.

In addition to the individuals who are mentally diseased, who are either psychotic or neurotic, there are individuals who are classed as *mentally deficient*, or *feeble minded.* These persons are commonly assumed to have been defective from the earliest stage of infancy in which the individual can be adequately examined. They are thus distinguished roughly from the mentally diseased, who are, in typical cases, those who have been at one time "normal," and have undergone deterioration. *Amentia*, therefore, may be described as congenital, whereas mental disease is acquired. This distinction should not be strongly stressed, however, since psychoses, and probably neuroses, are based on inherited tendencies or dispositions, or defects, and in the case of amentia, it is strictly speaking the constitutional defect or disposition that is inherited, not the amentia, which is only the functional

expression of the fundamental defect. Nor should we stress much the difference due to the early appearance of amentia, and the delayed appearance of mental disease. The typical psychoses sometimes appear in early infancy, and perhaps neuroses may also. Until we have much fuller knowledge of the causes of the predispositions to amentia and mental disease, the distinctions must remain on the rough practical basis, and even so, cannot be made very clear to those who have not actually worked with the cases of various types.

The responses of the feeble minded are in some respects like those of children of lesser years, and hence in practical classifications these defectives are often rated in terms of the ages of normal children. A defective person whose responses, when measured or estimated by some standard, are found to be like those of a normal child of six years, is then said to have a "mental age" of six. Defectives who are chronologically 16 years or over and who have "mental ages" between 8 and 12 are commonly called *morons;* those having "mental ages" from 3 to 7 are called *imbeciles;* and those having "mental ages" of 2 or less are classed as *idiots.*

Morons have been described as able to earn their livings under favorable circumstances, but not able to manage their social and economic affairs without direction and assistance. Imbeciles are described as able to carry out only the simplest tasks, and then only under constant supervision. Idiots can do little more than walk and feed themselves. Binet and Simon described idiots as unable to talk; imbeciles as unable to learn to read and write; and morons as unable to think (effectively).

All such classifications must be considered as tentative and suggestive rather than as final and exact. Further, it must not be supposed that a defective who is classed as of the "mental age" of 8 is really in the mental condition of a normal child of 8. A child whose actual age (chronological age) is 12, and whose "mental age" is 8, may not differ very much mentally from a normal child of 8; but the mind of a man the actual age of 21, and "mental age" of 8 differs very much from that of a normal 8 year old child. All that is meant by the "mental age" rating of defectives is that in a certain standardized test or tests, the defectives attain

the ratings which normal children of the ages specified would attain *in that test.*

The differences between the mentally defective and the normal individuals are commonly referred to as differences in *intelligence,* and the tests employed are designated as *intelligence tests.* "Intelligence," so used, means general efficiency of mental life, including effective integration and ability to learn. The intelligence tests employed are of various sorts, ranging from problems in arithmetic and logic down to the ability to make change in money and point to the eye and nose. The assumption in such tests is that all the individuals tested have been given the same chances to learn the process in which they are tested, and hence, that the amount they have learned measures the relative intelligence. It is obvious, therefore, that training must always be taken into account, and that in the cases of children, great skill and understanding of child psychology are required of one who should administer the tests with success.

In relatively few cases are the proximate causes of mental deficiency known. In some cases the secretion of the thyroid gland is insufficient; in some cases there are definite brain defects. In still other cases adenoids are the immediate cause of the defect. Defects of hearing and of vision are frequent causes of mental deficiency because they prevent learning. But in the great majority of cases the senses are normally efficient, and there is no defect in structure or function of the nervous system or the glands which can be shown in physical examinations. Yet the nervous system, in such cases, obviously does not function properly. Associations are formed with difficulty, and perceptual reactions modified but slowly. Somatic and visceral contents apparently receive more attention in the feeble minded than in the normal individuals. It almost seems that in the lower grades of mental deficiency the relations of external and organic perception are the reverse of those in the normal individual; that the feeble minded person is primarily conscious of his body, the outer world being but a confused background against which organic processes vividly appear.

The neural troubles of the mentally defective may therefore be summed up as defects of integration. These defects are ap-

parently hereditary, following the same laws of transmission from parents to children as do eye-color, teeth, and other physical characteristics. The defects are incurable, and hence those who are definitely feeble minded should not be allowed to propagate their kind. The individuals themselves may be made to learn by special training more than they would if left to ordinary school treatment; but this does not raise the intelligence of their children, although it may unfortunately enable them to marry and beget children.

The foregoing sketch includes only those mental diseases which have been generally recognized, which are relatively frequent in their occurrence, and concerning which there is a considerable amount of agreement among psychiatrists. In addition, there is a long list of pychoses and neuroses which have been described by different psychiatrists. Some of these diseases are rare, some are vaguely defined, and some are recognized only by certain schools of psychiatry. Some are merely sub-types of the general diseases we have described. There are also a number of specifically nervous diseases, such as chorea (St. Vitus' dance) and tabes dorsalis (locomotor ataxia), which have minor or secondary mental symptoms and effects.

APPENDIX II

SOME USEFUL REFERENCE BOOKS

This list includes books only. Reference to periodical literature should be sought in the *Psychological Index* (issued annually) and the reviews and summaries in the *Psychological Bulletin* (monthly). There are certain topics mentioned in the text on which no book references are given, although many books have been published, because those books are useful only to the well grounded and critical psychologist, who can sift a bushel of chaff from a grain of wheat. Certain other topics are omitted from the references merely because they are technical and remote from the general purpose of the text.

I. Psychological texts which present the subject from points of view significantly different from that of this text.

Breese, B. B.: *Psychology.* 1917.
Calkins, M. W.: *A First Book in Psychology.* 1910.
James, W.: *Principles of Psychology.* 2 vols. 1890.
Judd, C. H.: *Psychology: General Introduction.* 2d ed. 1917.
Ladd and Woodworth: *Elements of Physiological Psychology.* 1911.
Titchener, E. B.: *A Textbook of Psychology.* 1919.
Watson, J. B.: *Psychology from the Standpoint of a Behaviorist.* 1919.
Warren, H. W.: *Human Psychology.* 1920.

II. Anatomy, physiology and psychobiology.

Dunlap, K.: *An Outline of Psychobiology.* 2d ed. 1920.
Greenwood, M.: *The Physiology of the Special Senses.* 1910.
Herrick, C. J.: *Introduction to Neurology.* 1915.
Howell, W. H.: *A Textbook of Physiology.* 6th ed. 1915.
Luciani, L.: *Human Physiology* (transl. by Welby). 5 vols. 1911-17.
Schafer, E. A.: *Text Book of Physiology.* Vol. 2. 1900.
Schafer, E. A.: *The Endocrine Organs.* 1920.
Starling, E. H.: *Principles of Human Physiology.* 3d ed. 1920.
Quain's Anatomy: 11th ed. 4 vols. 1908.

III. The Cranial Senses.

(a) Taste and smell.

Collet: *L'odorat.* Paris, 1904.
Haycraft, J. B.: The sense of taste. The sense of smell. (In Schafer's *Textbook of Physiology*).

Henning, H.: *Der Geruch.* Leipzig, 1916.
Hollingworth and Poffenberger: *The Sense of Taste.* 1917.
Marchand, L.: *Le Gout.* Paris, 1903.
Sternberg, W.: *Geschmack und Geruch.* Berlin, 1906.
Zwaardemaker, H.: *Die Physiologie des Geruchs.* Leipzic, 1895.
(See also tables of contents of books in list II.)

(b) Audition.
Hamilton, C. G.: *Sound and Its Relaton to Music.* 1912.
Helmholtz H. von: *On the Sensations of Tone* (transl. by Ellis). 4th ed. 1912.
McKendrick and Gray: The ear. (In Schafer's *Textbook of Physiology*).
Miller, D. C.: *The Science of Musical Sounds.* 1916.
Pole, W.: *The Philosophy of Music.* 1910.
Watt, H. J.: *The Psychology of Sound.* 1917.
Watt, H. J.: *The Foundations of Music.* 1919.
Wood, H. J.: *The Physical Basis of Music.* 1913.
Zahm, J. A.: *Sound and Music.* 1892.
(See also tables of contents of books in list II.)

(c) Vision.
Burch, G. J.: *Physiological Optics.* 1912.
Edridge-Green, F. W.: *The Physiology of Vision.* 1920.
Greenwood, M.: Studies in special sense physiology. (In Hill's *Further Advances in Physiology.*) 1907.
Helmholtz, H. von: *Handbuch der Physiologischen Optik.* 3d ed. 3 vols. 1910.
Parsons, J. H.: *An Introduction to the Study of Color Vision.* 1920.
Rivers W. H. R.: Vision (in Schafer's *Textbook of Physiology*).
(See also tables of contents of books in list II.)

IV. The dermal, somatic and visceral senses and feelings.
Braun and Friesner: *The Labyrinth.* 1913.
Cannon, W. B.: *Bodily Changes in Pain, Hunger, Fear and Rage.* 1915.
Carlson, A J.: *The Control of Hunger in Health and Disease.* 1916.
Crile, G. W.: *The Origin and Nature of the Emotions.* 1915.
Darwin, C.: *The Expression of the Emotions in Man and Animals.* American ed. 1870.
Harvey: *The Feelings of Man.* 1914.
Head, H.: *Studies in Neurology.* 2 vols. 1920.
Hertz: *The Sensitivity of the Alimentary Canal.* 1911.
James, W., and Lange, C. G.: *The Emotions* (Psychology classics, vol. I). 1922.
Mosso, A.: The mechanism of the emotions (Appendix to Goddard, *Psychology of the Normal and Subnormal*).
Mosso, A.: *Fear* (transl. by Lough and Kiesow). 1886.
Mosso, A.: *Fatigue* (transl. by Drummond). 2d ed. 1906.
Shand, A. F.: *The Foundations of Character.* 2d ed. 1920.
Sherrington, C. S.: Cutaneous sensations. The muscular sense. (In Schafer's *Textbook of Physiology.*)
Ribot, Th.: *The Psychology of the Emotions.* (*Contemp. sci. ser.*) 1897.
(See also tables of contents of books in list II.)

V. Experimental methods and mental measurements.

Franz, S. I.: *Handbook of Mental Examination Methods.* 2d ed. 1919.

Stern, L. W.: *The Psychological Methods of Testing Intelligence.* (transl. by by Whipple). 1914.

Terman, L. M.: *The Measurement of Intelligence.* 1916.

Titchener, E. B.: *Experimental Psychology.* 4 vols. 1915.

Whipple, G. M.: *Manual of Mental and Physical Tests.* 2d ed. 1914.

Yerkes, R. M.: *A Point Scale for Measuring Intelligence.* 1915.

VI. Instinct and habit formation.

Drever, J.: *Instinct in Man.* 1917.

Colvin, S. S.: *The Learning Process.* 1911.

Ebbinghaus, H.: *Memory* (transl. by Ruger and Bussenius). 1913.

McDougall, W.: *Social Psychology.* 16th ed. 1921.

Pyle, W. H.: *Psychology of Learning,* 1921.

Watson, J. B.: *Behavior.* 1914.

Thorndike, E. L.; *Educational Psychology.* 3 vols. 1914.

VII. Mental diseases.

Bridges, J. W.: *An Outline of Abnormal Psychology.* 1919.

Church and Peterson: *Nervous and Mental Diseases.* 1908.

Diefendorf, A. R.: *Clinical Psychiatry.* 1912.

Dercum, F. X.: *Clinical Manual of Nervous Diseases.* 1914.

Janet, P.: *The Mental State of Hystericals* (transl. by Carson). 1901.

Janet, P.: *The Major Symptoms of Hysteria.* 1907.

Goddard, H. H.: *Feeblemindedness, Its Causes and Consequences.* 1914.

Rosanoff, A. J.: *Manual of Psychiatry.* 5th ed. 1920.

Seavill T. D.: *Clinical Lectures on Neurasthenia.* 4th ed. 1908.

Tredgold, A F.: *Mental Deficiency.* 2d ed. 1915.

Miner, J. B.: *Deficiency and Delinquency.* 1918.

Hollingworth, Leta: *The Psychology of Subnormal Children.* 1920.

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